IBA TECHNICAL REVIEW

18

Standards for Satellite Broadcasting

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IBA INDEPENDENT BROADCASTING AUTHORITY

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IBA INDEPENDENT BROADCASTING AUTHORITY

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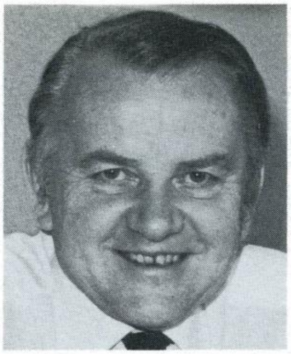
Introduction

by Baron Sewter



The IBA has completed nearly five years of research and development of satellite modulation and transmission equipments and systems for point-to-point links and for direct satellite broadcasting.

An earlier volume, *IBA Technical Review 11,* described the development of communication and broadcasting satellites, the fundamentals of satellite broadcasting, the ITU Plan for Space Broadcasting and the work of the IBA on satellite systems and associated terminal equipment as at mid-1978. This companion volume describes some of the further researches which the IBA has since undertaken in this field.

The world is on the brink of a new era in broadcast engineering. Several countries are already committed to introducing direct satellite broadcast services; the first satellite for this purpose is scheduled to be brought into service by either late 1984 or early 1985.

The many satellites already in use by broadcasting organisations provide only point-to-point communication services. North America and the USSR use satellites for the national distribution of television programmes, and most countries in the world use them for inter-continental transmissions of television programmes and news items.

The Radio Regulations of the ITU divide the world into three regions:

Region 1 mainly comprises Europe and the USSR.
Region 2 consists of the Americas.
Region 3 is mainly the Far East, including Australasia.

In 1971, the World Administrative Conference for Space Telecommunications revised such of the Radio Regulations as related to space telecommunications. In particular, they allocated specific frequency bands for special services, including satellite broadcasting.

In 1977, the World Broadcasting and Satellite Administrative Radio Conference (WARC-BS) (briefly termed WARC '77 in the chapters in this volume) established the fundamental technical characteristics for the planning and broadcasting of satellite services and defined the sharing criteria as between the direct broadcasting satellite and other services. It produced an outline frequency channel plan for Region 1 in the Band 11.7–12.5 GHz and for Regions 2 and 3 in the Band 11.5–12.2 GHz.

Article 12 of the Final Acts of the 1977 conference defined the provisions governing the broadcasting satellite services in Region 2 pending the formulation of a detailed plan. A Broadcasting Satellite Planning Conference for Region 2 has been arranged for 1983. Its agenda will include provision for a frequency (channel) plan for the 11.5–12.2 GHz Band.

The proposed coverage of Western Europe by direct broadcasting satellites is as shown in Fig. 1. The individual national coverages shown assume that domestic aerials will be of 0.9 m diameter, and that receiver performance and maximum transmitted power levels will be as prescribed by WARC '77.

In practice, the footprint could be much larger than here shown; more especially so if larger domestic receiving aerials (e.g. of 2.0 m diameter) were to be used or if much larger receive aerials were used for the feeding of cable networks. Further, the coverage area would be greater for those viewers willing to accept a quality of performance inferior to that considered in the planning; thus, satellite broadcasting services will create much more overlap between countries than exists at present with terrestrial television broadcasting.

The 800 MHz available for satellite broadcasting in Region 1 is divided into 40 television channels, each of which can accommodate one vision channel plus at least six sound channels in addition to a number of data channels. The sound channels can be used either to provide stereo or for simultaneous transmission in a number of different languages. Alternatively, up to 20 radio channels can be used in place of one

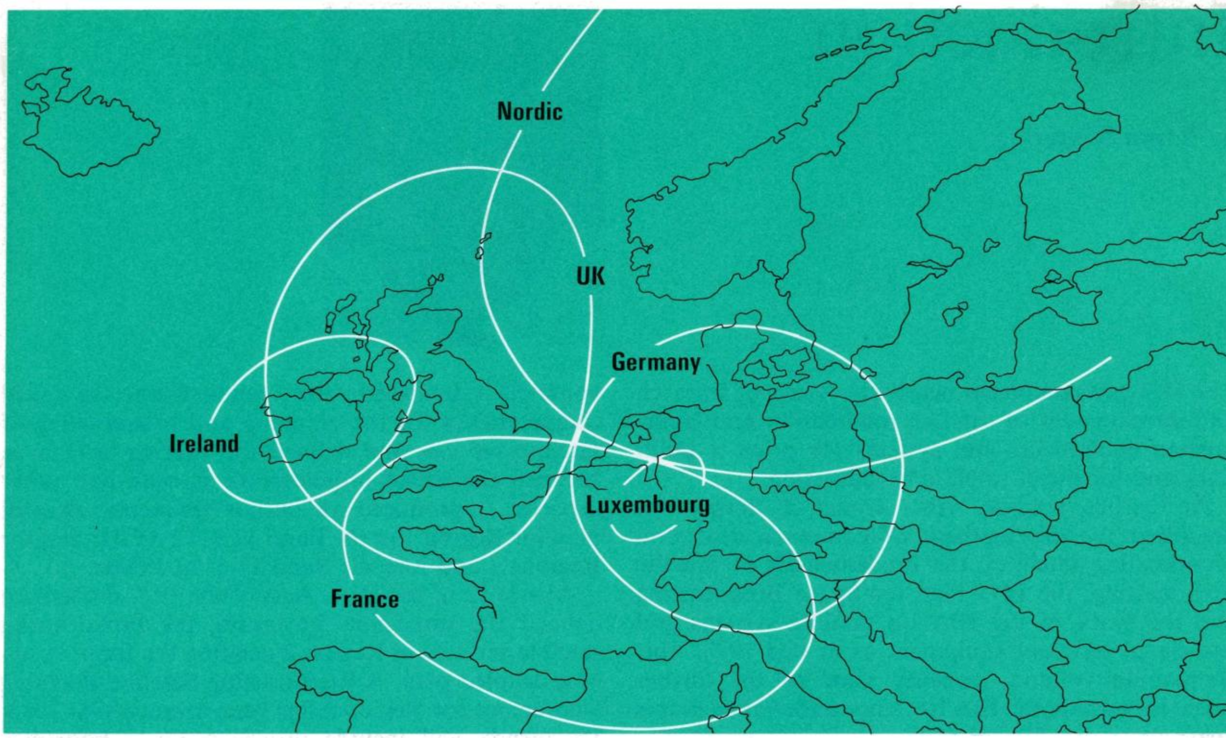


Fig. 1. The coverage areas predicted for some European satellites.

television service. Each broadcasting satellite can have a maximum of five television channels or equivalent radio channels.

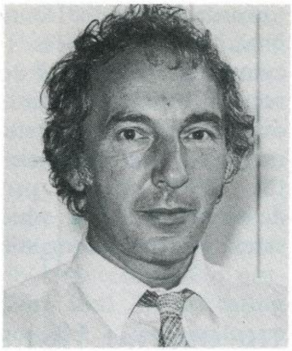
The five direct broadcasting satellite channels available to the UK in the 12 GHz Band, each providing coverage for the whole of the country, are especially suited to national broadcasting.

Therefore, it seems likely that terrestrial broadcasting will continue to be preferred for regional television services such as ITV. If either Band 1 or Band 3 is retained for terrestrial broadcasting in the UK it is possible that, in the long term, the UK could have: five national television services using broadcasting satellites, and five regional-type services using terrestrial broadcasting. The vital need is that, whatever system of modulation is adopted for the forthcoming satellite broadcasting service in Europe, it shall be adequate to meet fully the broadcasting requirements of the future.

This matter is of immediate national and international importance because the present time is likely to be the last opportunity of achieving for Europe (or, indeed, for the world) a common satellite modulation system which will give viewers a performance at least as good as that achieved by terrestrial means. The option chosen should also be suitable for future higher definition or extended definition services. The IBA considers that the use of either PAL or SECAM on the European broadcasting satellites would have major disadvantages and that, even though the time is short, a modulation system based on component analogue signals merits earnest consideration.

This volume details the IBA proposal for a satellite broadcasting modulation system with video analogue component signals. Such a system is proposed as a standard, at least for Europe. Some of the chapters in this volume give details of measurements made by the IBA when using the OTS satellite, and a description is given of the experience gained in the use of the first transportable up-link available in Europe. It is hoped that the IBA proposals, measurements and studies will lead to European standards, and possibly to world-wide standards, for point-to-point communication satellites and for the direct broadcasting satellites which are soon to be brought into service.

TERRY LONG received his early training at EMI Research Laboratories prior to joining the General Dynamics Corporation in California where he was engaged on defence projects. While in the USA he completed a programme of postgraduate studies at the University College of Los Angeles. Following his return to the United Kingdom in the mid-1960s he joined GEC Electronics at Stanmore where he led the group which developed the tracking receiver for the Rapier defence system. He joined the IBA in 1970 and was promoted to Head of Radio Frequency Section in 1973. He has been Head of Experimental and Development Department since 1978.



Satellite Developments and Opportunities

by T. J. Long

Synopsis

This chapter examines the total broadcasting communications scene in relation to satellite requirements and design. There is a strong case for considering new modulation systems for the Satellite Broadcasting Service. Recent IBA work on satellite communications is here summarised, and an outline is given of a Multiplexed Analogue Signals System which merits consideration as a European and possibly World Standard.

The scene is now set for a revolution in broadcasting engineering. The decade from the mid-1980s is likely to be a period when the long predicted impact of broadcasting satellites becomes a reality, transforming the way people communicate with each other, increasing the number of television, sound and data channels available and providing the means of giving the public 'instant information' on an unprecedented scale. This article sets a backcloth to the role of satellites as seen in 1982 and describes the IBA's contribution to the new era in broadcasting engineering.

The development of the space shuttle in the USA and of the Ariane rocket in Europe will provide the means of launching much larger spacecraft than hitherto, carrying very sophisticated and powerful telecommunications payloads. Ariane III, for example, will be developed by the European Space Agency (ESA) to have a launching capability of 2,400 kg into an elliptical orbit, which rises to an apogee equal to the geostationary distance, and can be circularised by a single 'burn' of the apogee boost motor on board the satellite. The service module for the large satellite (L-SAT) being designed by ESA to match the Ariane III launcher capability will offer some 300 kg of payload capability with a d.c. power provision up to 7 kW, whereas the European Communications Satellite (ECS) type platform to be launched in 1982 has a payload carrying capability of only 100–150 kg and a maximum d.c. power provision of less than 1 kW. The L-SAT service module will thus be capable of carrying a sufficient payload to provide five broadcast television channels at full power-loading, in conformance with the World Administrative Radio Conference (WARC) '77 plan for Regions 1 and 3, together with the capability of also carrying television point-to-point transponders, if required. The use of larger service modules is an inherent part of the USA's Space Shuttle programme plans, although, at present, the broadcasting usages are less defined in the USA because the detailed frequency plan for Region 2 is to be established at a Planning Conference to be held in 1983.

A European satellite broadcast transmission standard based on the WARC channel plans is required urgently to meet the satellite broadcast requirements of the next 20 years. If the modulation system used does not satisfactorily take account of the likely developments in the related areas of picture display, storage and manipulation, or fails to ensure

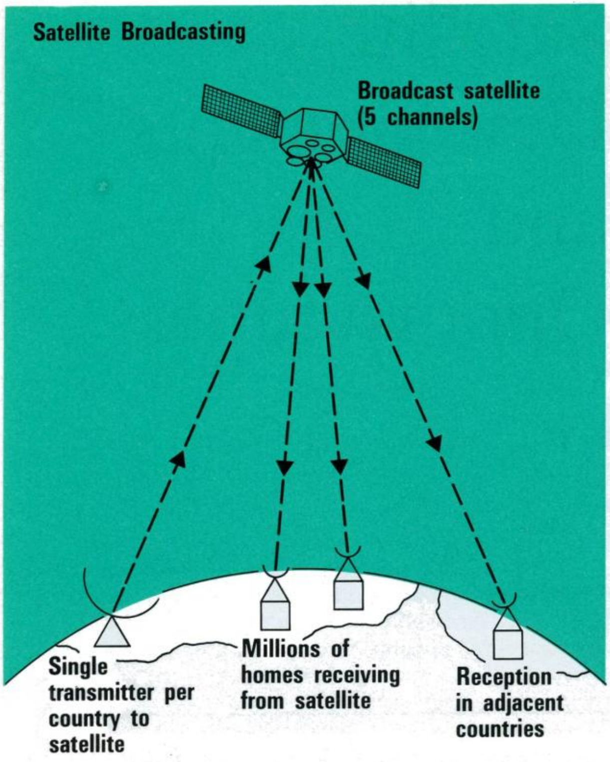


Fig. 1. Direct Broadcasting Satellites—a possible scheme.

that the allocated channels are used efficiently, both today and tomorrow, then broadcasting engineers will be seen to have failed in one of their prime responsibilities.

The new standard needs not be compatible with terrestrial monochrome transmission standards devised several decades ago. It could provide four or more sound channels, one or more high data rate teletext channels and an analogue form of vision signal. The analogue component picture transmission proposed is suitable for both viewing on existing 625-line receivers with minimal processing, and (after more elaborate signal processing) for viewing on large screens in an extended or higher definition form.

The system to be used should give the picture, sound and data signal qualities at least as good as, and preferably better than, those achieved by terrestrial broadcasting means. Against this background, broadcasting experiments with OTS must be seen as a proving exercise aimed at gaining confidence in the new satellite and receiver technology, and also as a series of important steps towards laying the foundations for a range of new broadcasting services. The OTS, having almost completed its role as a test bed for many projects related to point-to-point network links and for some direct broadcasting studies, continues to be an extremely useful vehicle for proving experiments in the IBA's current programme of research and development work which is aimed at establishing satellite broadcasting standards.

THE ORBITAL TEST SATELLITE (OTS)

OTS 2 was designed and manufactured by a European Consortium and launched in May 1978. (OTS 1 was lost in an unsuccessful attempt at launch the previous year.) It was placed in a geostationary orbit at 10°E and has a station-keeping accuracy of $\pm 0.1°$. It is the forerunner of an operational ECS system which is expected to commence service in 1982. OTS 2 weighs 857 kg and measures 8.6 m (across the solar cell panels) by 2 m and 2 m. The design lifetime is five years. The solar panels provide a d.c. power of 600 W which powers four main transponders, two of 120 MHz bandwidth and two of 40 MHz bandwidth. The 120 MHz transponders are oppositely polarised (for frequency re-use experiments) and are connected to the high gain 'Spotbeam' aerial of the satellite, providing a down-link Effective Isotropic Radiated Power (e.i.r.p.) of 45 dBW (in the UK) for each polarisation. The down-link centre frequencies are each 11.640 GHz. The two 40 MHz bandwidth transponders, which use the lower gain 'Eurobeam A' aerial, are also oppositely polarised and provide an e.i.r.p. of 37 dBW with down-link centre frequencies of 11.510 GHz. All four wideband transponders are linearly polarised.

The satellite contains two circularly polarised CW beacons operating at 11.786 GHz, (also orthogonally polarised). One beacon is constantly in operation and the other is available as a stand-by (this enables cross-polarisation measurements to be made). A transponder having a bandwidth of 5 MHz is also available. This can be used for narrowband transmissions and for up-link/down-link propagation tests. Its e.i.r.p. is 40 dBW and it uses a centre frequency 11.795 GHz.

A linearly polarised satellite telemetry beacon, operating at 11.575 GHz, is also available for propagation experiments. The up-link frequency band for OTS is 14.1–14.5 GHz. Details of the IBA's facilities for receiving signals from OTS 2 were given in *IBA Technical Review 11*.

The test programme for OTS 2, now nearing completion, is organised by INTERIM EUTELSAT set up by the Conference of European Postal and Telecommunications Administrations (CEPT). So far as broadcasting is concerned, the two main experimental programmes are propagation and television measurements.

About 40 organisations are represented on a EUTELSAT group controlling propagation tests. These organisations are mainly Universities, Government Research Establishments and Broadcasting Organisations, including the IBA. The analogue television measurement programme (now completed) was organised by a specialist group of EBU subgroup R3, on which seven Broadcasting Organisations, including the IBA, were represented. The digital television measurement programme (also completed) was organised by an EBU/EUTELSAT group, which was also responsible for co-ordinating all tests for Eurovision.

WARC 1977

This conference, held in Geneva, was responsible for the planning of national direct broadcast satellite services for each country in Europe. The plan came into effect on 1st January 1979 and is valid for fifteen years from that date.

The main aspects of the plan are as follows:

(*a*) the division of the 12 GHz band into 40 channels each of 27 MHz bandwidth with a minimum channel separation of 19.8 MHz. Each channel is designed to carry either one television signal with accompanying sound or at least twelve sound-only signals;

(*b*) the allocation of five of these 27 MHz channels to each country;

(*c*) the allocation of an orbital position in the geostationary orbit to each country;

(*d*) the specification of maximum e.i.r.p. levels and aerial beamwidths for each downpath transmission;

(*e*) the use of polarisation discrimination to minimise interference between adjacent transmissions—this involves the allocation of right-hand or left-hand circular polarisation to the transmissions from each satellite.

The plan does not specify the method of modulation to be used. It is important to note that any modulation system is permissible, provided that interference to other services is not worsened. The orbital positions are based on a minimum spacing of 6° between satellites; longitudinal positions provide a minimum angle of elevation of 20° of each national satellite from its coverage area. A convenient time of day, in terms of broadcast transmissions, is incorporated in the plan for the loss of signal due to satellite eclipse (a loss of signal which occurs when the earth's shadow cuts off the sun's radiation from the solar panels; the resulting duration of power-loss will be between one and two hours daily for a twice-yearly period of several weeks).

The satellite e.i.r.p. and beamwidth specifications provide a flux density of -103 dBW/m^2 at the edge of each coverage area for 99% of the worst month. This flux density provides a carrier-to-noise ratio of 14 dB in individual domestic receivers with a figure of merit of 6 dB/K.

Due to the geographical distribution of European countries, considerable overlap occurs between the coverage areas of adjacent national satellites. Since the plan was drawn up, developments in improving receiver sensitivity have taken place and these, together with the possible use of larger diameter dishes, will increase the extent of the overlap. Thus, multinational viewing of satellite programmes, particularly in adjacent countries, is a strong possibility.

Table 1 shows the orbital position, channel assignments and polarisations specified by the plan for the countries of Western and Southern Europe.

GENERAL CRITERIA

The key factors which need to be considered in judging the merits of proposed transmission standards for satellite broadcasting in Europe can be summarised as follows:

(*a*) the optimum method of achieving a picture quality equal to the best that viewers receive on terrestrial broadcast services and which will at least equal the picture quality they will get from other sources such as cable systems and domestic videotape recorders;

(*b*) the number of high quality television and sound channels receivable by the viewers using either (i) relatively simple equipment designed for national programme reception only, or (ii) more elaborate equipment designed for national and adjacent country viewing;

(*c*) the capacity and quality of the data services receivable;

(*d*) the potential for introducing compatible improvements to the system as receiver and display technology develops;

TABLE 1: ORBITAL POSITIONS, CHANNEL ASSIGNMENTS AND POLARISATIONS* FOR COUNTRIES OF WESTERN AND SOUTHERN EUROPE

ORBITAL POSITION	LOWER HALF (11.7–12.1 GHz)		UPPER HALF (12.1–12.5 GHz)	
	Left-hand circular polarisation	Right-hand circular polarisation	Left-hand circular polarisation	Right-hand circular polarisation
37° West	Andorra 4, 8, 12, 16, 20	San Marino 1, 5, 9, 13, 17		Monaco 21, 25, 29, 33, 37
		Liechtenstein 3, 7, 11, 15, 19		Vatican 23, 27, 31, 35, 39
31° West	Portugal 3, 7, 11, 15, 19	Ireland 2, 6, 10, 14, 18	Iceland 21, 25, 29, 33, 37	
		United Kingdom 4, 8, 12, 16, 20	Spain 23, 27, 31, 35, 39	
19° West	West Germany 2, 6, 10, 14, 18	France 1, 5, 9, 13, 17	Switzerland 22, 26, 30, 34, 38	Belgium 21, 25, 29, 33, 37
	Austria 4, 8, 12, 16, 20	Luxembourg 3, 7, 11, 15, 19	Italy 24, 28, 32, 36, 40	Netherlands 23, 27, 31, 35, 39
5° East	Finland 2, 6, 10	Turkey 1, 5, 9, 13, 17	Nordic† 22, 24, 26 28, 30, 32, 36, 40	Cyprus 21, 25, 29, 33, 37
	Norway 14, 18			
	Sweden 4, 8	Greece 3, 7, 11, 15, 19	Sweden 34	Iceland‡ 23, 27, 31, 35, 39
	Denmark 12, 16, 20		Norway 38	

* The polarisation is said to be 'right-hand circular' or 'left-hand circular' when the electric vector of the propagating wave rotates clockwise, or anticlockwise, respectively, as seen from the transmitting point.
† Eight channels in a wide beam covering the Nordic countries: these are assigned to Finland (22, 26), Sweden (30, 40), Denmark (24, 36) and Norway (28, 32).
‡ Beam covers Iceland, the Azores and part of Greenland. Channels 27 and 35 registered under Denmark.

(*e*) the efficiency of the system in terms of its utilisation of the available spectrum;

(*f*) the cost of receiving equipment:

(i) for converting the transmitted broadcast signal to a form suitable for use with receivers designed prior to the standard being adopted;

(ii) for a hierarchy of standard receiver designs which will emerge, following the adoption of the standard, for add-on equipment to take advantage of new services;

(iii) for extended (or higher) definition services and large-screen displays which will become practical with the rapid changes in technology.

THE USE OF PAL AND SECAM

In considering the transmission standard that should be adopted for satellite broadcasting it would be useful to examine whether continued use of terrestrial PAL and SECAM standards would meet all requirements. Account should be taken of the fact that the WARC '77 plans 'do not preclude the use of other modulation characteristics'—(Final Acts WARC 1977, p. 93). The main OTS 2 broadcast television experiments have used either PAL or SECAM modulation, but the IBA is completing tests on a multiplexed analogue components system.

Certainly the test results obtained by OTS 2 experimenters have largely borne out the predictions made in the WARC '77 plan both for propagation effects and for the quality of television reception. The OTS propagation test results are in broad agreement with the prediction curves assumed by WARC '77, confirming, for example, that with atmospheric precipitation taken into account, in the UK the received signal will remain within 1.5 dB of its clear weather value for 99.75% of the time.

The OTS 2 television test results have also indicated the performance that would be obtained with terrestrial PAL and SECAM standards using a single analogue sound carrier. With a carrier-to-noise ratio of 14 dB or better, picture noise is judged to be 'perceptible but not annoying' (grade 4) and the sound quality adequate (weighted signal-to-noise ratio 44.5 dB). The quality of the PAL (or SECAM) vision signal received leaves much to be desired, because of the chroma signal-to-noise ratio that would be achieved, particularly on the fringe of the reception area with the inherent cross-colour and cross-luminance problems of PAL and SECAM remaining as an annoying effect, particularly on certain types of pictures. Even with this rather simple signal, the results show a significant interaction between the vision and sound signals owing to system non-linearity. When a second sound sub-carrier is added clear patterning from intermodulation between the colour and sound sub-carriers was observed on the pictures at a number of terminals, the overall

degradation of the picture being judged to be about 1–2.5 dB when the second sub-carrier was present.

Results obtained with a digitally modulated sound carrier, replacing the terrestrial standard, were more encouraging. Several high quality sound channels were transmitted, and the observed effects on the vision signal were no worse than those obtained with the lower quality single-channel analogue sound system.

In summary then, the OTS 2 television test results support the view that the terrestrial PAL/SECAM and sound systems are usable but leave much to be desired for satellite broadcasting. The service so provided would have the following technical defects/disadvantages:

— inherent PAL and SECAM imperfections would remain;
— chroma signal-to-noise ratios would be worse than for the current terrestrial service at the periphery of the service areas;
— analogue sound channels would have inadequate performance and/or could cause impairment of the vision signal;
— the potential for introducing future improvements would be very limited.

These technical limitations have been widely recognised by the Broadcasting Organisations around the world. Working Parties of the EBU are currently studying a range of proposals for new vision, sound and data transmission standards. Many of these proposals concentrate on methods of transmitting a high capacity digital signal accompanying the vision and capable of carrying several channels of high quality sound, or a mixture of sound and data. These sound and data system proposals fall into four groups:

— systems involving one or more FM or digitally modulated sound sub-carriers; the latter added to the video signal before FM modulation;
— systems involving the time division multiplexing of digital sound information into the television line-blanking period, the multiplexed signal being used to frequency modulate the carrier;
— systems whereby the digital sound is used to modulate the transmitted carrier in the television line-blanking period and the active line part of the television baseband signal used for frequency modulating the transmitted carrier during the remaining period. In such a system special arrangements are required to convey television synchronisation and sub-carrier burst information;
— digital picture and sound, time division multiplexed using DPCM for video encoding.

None of these proposals, apart from the last group, takes into account the important question of the vision transmission standard and the balance that should be struck between the vision, sound and data signals; this balance is constrained by the satellite channel bandwidth.

If one ignores the last group as being no solution for the near future (on the grounds that the transmission of pictures in digital form requires complex equipment which will be relatively expensive for some time to come), the urgent need is for an analogue transmission standard for the vision signal.

PAL or SECAM are certainly not optimum technical solutions for satellite broadcasting. They are standards that were devised more than 20 years ago for the terrestrial services under the constraint of strict compatibility with the then existing monochrome services. They suffer from the well-known impairments of cross-colour and cross-luminance, and their unsuitability for use in FM channels or for signal processing is well-known. In addition, SECAM and the several variations of PAL are of essentially national origin and application, whereas satellite broadcasting will be inherently international in character.

The IBA considers that PAL and SECAM are unsuited as a vision transmission standard for direct satellite broadcasts to Europe. An analogue component system seems to have considerable advantages and the IBA's proposed MAC system is described in the accompanying article by Lucas and Windram.

INFLUENCES ON SATELLITE SYSTEM DESIGN

Developments in direct satellite broadcasting cannot be considered in isolation, because the total broadcasting requirements can affect the satellite system design. What may happen in the studios, on permanent and temporary terrestrial links and on satellite OB links, has to be taken into account.

Terrestrial Network Influences

At present, all point-to-point television links that are in use in Europe are terrestrial and use analogue signal format. Switched networks are unlikely to be suited to satellite communication links. Networks, such as that provided for ITV, must have their configuration changed to meet the minute-to-minute programme requirements, the latter resulting from the regional

nature of the service. Satellite point-to-point links could not give the flexibility required at many network nodes. Networks which are used as a fixed grid, such as that required for distributing Channel Four via fourteen Regional Programme Companies could well be provided by a communication satellite, if the economics and time-scale permitted.

British Telecom plans to start re-equipping its main intercity analogue systems with digital equipment by the mid-1980s; and the UK telecommunications long-distance network will become almost completely digital during the following decade. It is envisaged that, for an interim period from say 1985–1995, it will be necessary to interconnect analogue and digital links in the terrestrial distribution and contribution television networks. There could be advantages in maintaining the component signals over the analogue terrestrial and earth station connecting links used during this interim period. One attractive way of achieving this could be to adopt analogue component coding. Transmission performance advantages could result from converting to an analogue component signal for transmission over all terrestrial microwave links because these, like the direct broadcasting satellite system, employ FM.

Very Long Distance Links

The use of communications satellites to provide analogue point-to-point television links has been well established for many years; and, almost every day, news pictures are seen from other continents around the world. In North America, communication satellites are used for national distribution to stations and local area cable networks in town and city. With the long distances involved in North America, satellite communication links have proved very attractive economically. However, cable distribution to homes has been used less in Europe, although the position could change with new requirements in the direct satellite broadcasting era. One way in which such a system might develop would be in the distribution of signals from satellite community receiving aerials to groups of houses or blocks of flats. At the present time, fibre-optic cables are becoming economically competitive with copper coaxial cables for such distribution.

News and Outside Broadcast Coverages

Up to the present time, television outside broadcast links have been provided by means of temporary microwave point-to-point FM links and/or video transmissions over telephone, balanced-pair and coaxial-pair cables. The planning and setting-up of such temporary links is time consuming. Satellite OB links could undoubtedly have a part to play in the future provision of news and outside broadcast coverages.

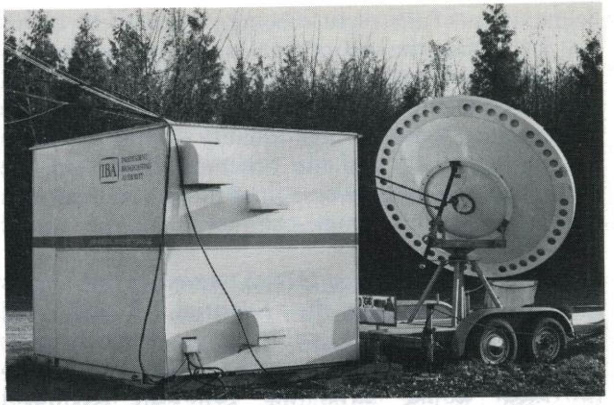


Fig. 2. The transmitting aerial and equipment cabin of the transportable up-link used by the IBA at Crawley Court, Winchester, and elsewhere.

The IBA pioneered the first transportable satellite up-link in Europe and an article in this *Review* describes its design and the experience gained. It is difficult to foresee how many satellite up-links will be required for a regional television service, such as ITV. With over 30 OB units serving ITV it is likely that the majority will continue to be connected by temporary microwave links for many years to come. It seems likely that a few satellite OB links could prove extremely valuable for major OB events and for serving news and OB locations which are difficult to connect by terrestrial microwave techniques.

Digital Vision Transmission Aspects

Digital vision transmission techniques can reduce the interference between adjacent satellite systems. The use of scrambling in a digital system can give a transmitted spectrum that is flat; FM systems, even with energy dispersal, tend to exhibit rather spiky spectra, with peaks several dB above the average power level. The digital coding equipment designed by the IBA has greatly assisted the general appraisal of the relative advantages of digital and analogue satellite link modulation techniques.

Satellite Communication Channels

In Europe the terrestrial links are designed to meet a digital hierarchy of 2.048, 8.448, 35.70 and

140 Mbit/s. However, the wideband satellite transponder channels are standardised to either 40 MHz or 80 MHz which, with digital techniques and using Quarternary Phase-Shift Keying (QPSK), correspond to bit rates of 60 or 120 Mbit/s respectively. 60 Mbit/s Satellite Transmission Tests have been carried out by the IBA. These have proved that small dish aerials, e.g. of 3 m diameter, are suitable for up and down-links with OTS 2 or satellites having similar transmitter powers.

Frequency Re-use on Communication Satellites
Frequency reuse techniques can be achieved by using dual orthogonal polarisation techniques to provide a second channel on the same frequency; a specified level of cross-polar isolation has to maintained. The IBA has studied this reuse technique and a proposed 'adaptive cross-polar cancellation' feature.

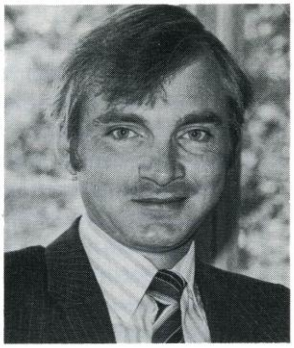
FUTURE IBA STUDIES AND TESTS
Further studies and measurements are already being undertaken to establish:

— the optimum multiplex and modulation standards for vision, sound and data channels using analogue transmission for the vision signal and either analogue or digital transmission for the sound and data signals;
— the optimum digital video component codecs, for permament and temporary OB links;
— the achievement of less bulky dish aerials for transportable up-links, e.g. segmented foldable aerials.

This work should help the world's Broadcast Organisations to make the most effective use of broadcast engineering in the decades ahead. The public will know, from performance and cost, whether the right decisions have been made.

Standards for Broadcasting Satellite Services

by K. Lucas and M. Windram



KEITH LUCAS, M.Sc., Ph.D., graduated in 1967, and afterwards spent four years at Southampton University on research in the field of Artificial Intelligence and Adaptive Control Systems. He was then employed by the Plessey Company and worked on a number of defence projects. In 1974, he joined the Authority's Experimental and Development Department where, within the Automation and Control Section, he was engaged in the development of ORACLE. He became Head of Video and Colour Section in the early part of 1978.

MICHAEL WINDRAM, MA, Ph.D., C.Eng, MIEE, graduated in 1966 and afterwards spent a further three years at Cambridge University on research in the field of Radio Astronomy. In 1969, he joined Marconi Elliott Avionic Systems Ltd. to work on Radar system development. In 1971 he joined the Authority's Experimental and Development Department where, within the Radio Frequency Section, he was involved in the development of the Adaptive Aerial system and tunable equipments. He became Head of Radio Frequency Section in early 1978. He is married, has two sons and lives in Winchester.

Synopsis
Direct television broadcasting by Satellite will be a reality in Europe by the mid-1980s. The plans for the service were defined by the 1977 WARC, but are at present based on conventional PAL/SECAM signals, which provide little opportunity for development. Fortunately, the WARC plans permit use of other modulation schemes within certain rules. The IBA therefore proposes a 'Multiplexed Analogue Component' (MAC) signal, which could be used as the basis of a single European Standard for Direct Satellite Broadcasts. Such a system, incorporating separate component signals, could in due course provide high-quality signals suitable for large-screen and high-definition displays.

The 1977 World Broadcasting Satellite Administrative Radio Conference (WARC '77) established plans for direct television broadcasts in Europe and throughout Regions 1 and 3. Most countries in Europe were each assigned five channels within the frequency band 11.7 to 12.5 GHz. Each channel is 27 MHz wide and is planned to carry a video signal with associated FM sound sub-carrier. These signals frequency modulate the 12 GHz carrier (using suitable pre-emphasis networks). Although the spacing between channels is only 19.18 MHz, adequate protection from co-channel interference and from adjacent channel interference is provided by the choice of signal polarisation and by the directional properties of each receiving aerial.

All current proposals for direct-broadcast satellite transmissions in Europe assume use of a conventional PAL or SECAM video signal. However, it is

important to note that the WARC '77 plans 'do not preclude the use of other modulation signals having different characteristics . . . provided that the use of such characteristics does not cause greater interference than that caused by the system considered in the plan . . .'

Within the European Broadcasting Union, modifications for providing additional channels for sound and data (possibly by use of a digitally modulated sub-carrier) are now being studied. This chapter questions whether the assumptions with respect to the video signal (viz, the use of conventional PAL or SECAM) are justified, or if (as with the sound channel) consideration of suitable alternatives is desirable.

ALTERNATIVE MODULATION SCHEMES

The use of conventionally coded composite signals was a natural assumption when the WARC '77 plans were devised. At that time (and, indeed, today) the majority of programmes were manipulated and stored on magnetic tape in the composite signal form. Also, there remains the firm intention that prospective viewers of the satellite service shall be spared the cost and inconvenience of purchasing new reception devices beyond the essential dish aerial and satellite converter unit. Therefore, the satellite signals will be interfaced to existing domestic UHF receivers which, necessarily, already contain either a PAL or SECAM decoder prior to the display unit. However, it should not be assumed that the satellite signals will be compatible (in the normal sense of that term) with existing receivers; because, whereas terrestrial VHF/UHF television signals employ amplitude modulation, the satellite signals will be transmitted by frequency modulation of a carrier in the region of 12 GHz. Hence, each domestic installation will require a satellite television transcoder, the minimum complexity of which is illustrated in Fig. 1. However, as will be shown, existing proposals imply that, for many satellite broadcast users, increased complexity of reception equipment will be unavoidable.

Whereas VHF and UHF broadcasts involve only very limited overspill from any one country to another, the satellite plan will produce significant overspill. The satellite broadcasts for any one country will cover major areas of other countries. Thereby, multinational reception will become an important factor. Under the existing proposals, even those viewers prepared to install suitable aerials might be unable to receive broadcasts from other countries because of the incompatability between the PAL and SECAM signals (and indeed between the different versions of PAL). To receive such broadcasts, a

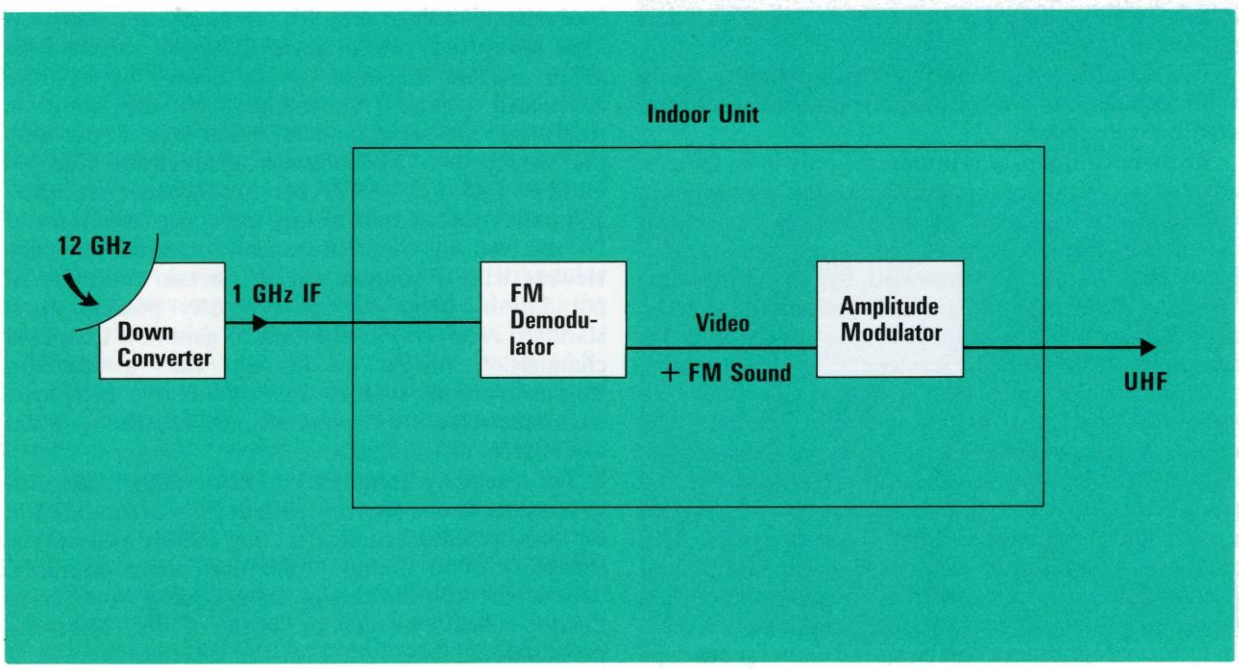


Fig. 1. A basic satellite converter.

viewer with a single-standard receiver would need to adopt one of the following alternatives:

(i) to purchase, in addition to a satellite converter, a multi-standard receiver;

(ii) to purchase a satellite converter containing a PAL/SECAM transcoder, although this would degrade the received picture quality. (The manufacture of such transcoders is now under consideration, because use of these might become the normal arrangement in countries with mixed language populations).

It is of interest to note that, despite the current differences in video coding standards, attempts are being made within the EBU to standardise the audio aspects of the satellite channels. If these efforts prove successful, they will imply, even for reception of national transmissions, transcoding within the satellite converter. This will be necessary in order to match the standardised audio format to the various specifications of existing terrestrial transmissions. For example, the UK uses a sound carrier of 6 MHz FM, Germany uses 5.5 MHz FM, and France 6.5 MHz AM.

Compatibility with existing receivers or aerial systems is impossible (the satellite signals being 12 GHz FM). Compatibility with existing baseband signals (PAL or SECAM) does not remove the need for a satellite transcoder, and leads immediately to incompatibility between the satellite signals of the nations of Europe.

Therefore, the question of compatibility is a complex one, and relates to the sophistication of the satellite transcoder.

Receiver complexity is important only in so far as it affects the critical parameters of cost and convenience, but economies of scale may be equally important. Nevertheless, it has hitherto been assumed that these parameters would be optimised by an appropriate choice of either PAL or SECAM modulation, thereby avoiding unnecessary transcoding in the receiver for reception of the national service.

Developments since 1977 give cause to doubt the validity of arguments in favour of PAL and SECAM coded satellite signals. First, the rapid advances of digital technology applied in television studio equipment have led to an agreement throughout Europe on a standard for digital video signals. This standard is based exclusively on separate-component (luminance, and colour-difference) signals rather than on a composite-coded signal such as PAL or SECAM. In future, programmes will be stored on magnetic tape in a high-quality YUV format. Even where recordings have been made in PAL form, high quality YUV signals can be generated prior to transmission by use of advanced (field-store) decoders which have already been developed. These decoders can provide YUV signals of a quality much higher than is achieved in existing receivers. Certain picture impairments (such as cross-colour) which are inevitable with composite decoders, would not occur in such a YUV format.

A second development which has recently taken place is that television manufacturers are beginning to introduce a direct separate component interface to the display as a standard feature of design. Increasingly, the receiver is being used as the display for systems other than broadcast television. Cassette recorders, television games and, in the future, videodisc, data systems and satellite converters will all compete for the screen. At present, such systems must be provided with PAL/SECAM encoders and UHF modulators in order to gain access to the receiver through the aerial terminal. Internally, these circuits may code the picture in ways which are unrelated to PAL/SECAM. The need for PAL/SECAM coder and UHF modems not only increases costs unnecessarily, but also introduces very considerable impairments to the picture. It can be confidently expected that the practice of providing a YUV or an RGB interface to the domestic receiver will be universally adopted for non-portable colour sets. *This development presents an opportunity to create a single European standard for direct satellite broadcast services based on separate component signals.* An interface to the domestic receiver at the separate-component level is the only one which will be common throughout Europe. Unlike PAL or SECAM broadcasts, separate-component broadcasts by any European nation could be received in other European countries by any viewers with a suitable aerial. Certain multilingual populations (who do not normally possess dual-standard receivers) would thereby gain new television channels. It might be thought that a common standard of this type is well suited to a broadcast technique which, by its nature, crosses the national boundaries of Europe.

The foregoing arguments do not establish the need to consider a separate-component form of modulation for direct satellite broadcasts; they merely indicate the feasibility of so doing should that prove desirable. Any departure from composite encoding would have to be based on one or both of the following propositions:

(i) That the current proposals for PAL/SECAM

using frequency modulation are, in some respects, inadequate.

(ii) That a departure from PAL/SECAM modulation would provide an improved public service without significantly increasing costs.

These propositions are examined in detail in the following sections.

The PAL/SECAM FM SIGNAL–DEFECTS

The composite signals in use today were invented about 20 years ago, and were appropriate to the technology available at that time. They do, however, introduce well-known picture impairments such as cross-colour and cross-luminance, although modern technology can be employed to reduce these defects (or, rather, to trade them for less objectionable ones). The signals were designed for strict compatibility with monochrome receivers, taking account of the problems of noise and distortion which occur in AM transmissions. However, they are very much less suitable to the problems of noise and distortion which will occur in FM transmissions. Susceptibility to noise will first be considered.

For any broadcast system, the required transmission power is defined by the signal-to-noise ratio which can be achieved at the limits of the intended service area.

In amplitude modulated signals, the power spectrum of the noise is approximately constant throughout the frequency range of the received baseband video signal as shown in Fig. 2a. In the PAL and SECAM signals, the amplitude of the colour sub-carrier was determined with due regard to creating a reasonable balance between the signal-to-noise (S/N) ratios in the decoded luminance and colour-difference signals, as well as balancing the defects of cross-colour and cross-luminance. In FM systems, the noise voltage spectrum is triangular (Fig. 2b) increasing linearly from zero (at d.c.) to the edge of the band. The colour sub-carrier, with its sidebands, resides at the top of the band (3.5–5.5 MHz), and is therefore subjected to high levels of noise. Consequently, there is an imbalance between the signal-to-noise ratios which may be achieved in the luminance and chrominance signals which amount to 11 dB (weighted) unless pre-emphasis filters are used to boost high frequencies.[1] Unfortunately, the introduction of a pre-emphasis network creates almost as many problems as it solves. The bandwidth of an FM signal is roughly proportional to both the amplitude and the frequency of the modulation. High levels of pre-emphasis, therefore, rapidly cause interference to adjacent channels or (if out-of-band products are removed by filtering) high levels of distortion. In fact, significant levels of pre-emphasis are normally applied to PAL signals on FM channels, but this does not achieve a balance between the weighted luminance and chrominance noise. The agreed pre-emphasis network (CCIR recommendation 405–1) improves the chrominance S/N ratio by $12\frac{1}{2}$ dB, and that of the luminance[2] by $1\frac{1}{2}$ dB. Consequently an imbalance of about 9 dB remains in favour of the luminance signal. Experiments show that (in terms of weighted signal-to-noise ratios) one can accept more chrominance noise than luminance, although the degree of tolerance is highly picture dependent, and amounts to

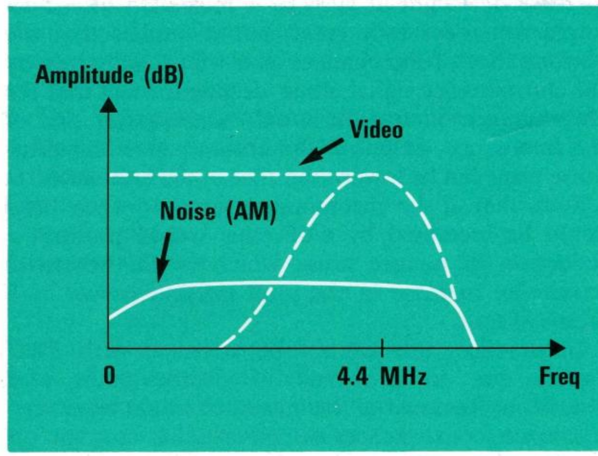


Fig. 2(a). The noise spectra associated with AM signals.

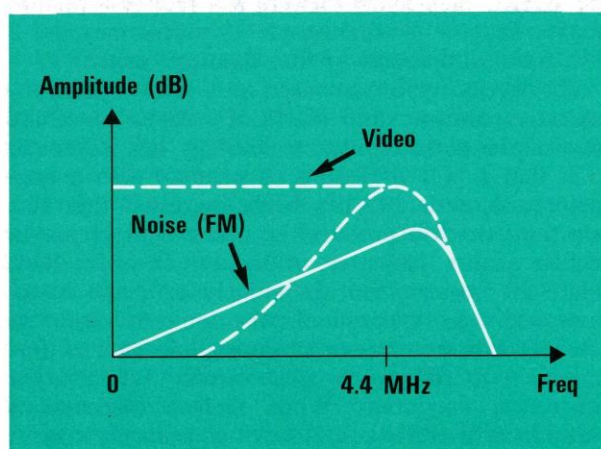


Fig. 2(b). The noise spectra associated with FM signals.

only 2–3 dB for the V signal. Colour noise (particularly below 800 kHz) will therefore be the major source of picture impairment.

The effect of the mismatch between the FM noise spectrum and the requirements of the PAL sub-carrier signal is such that the received pictures will be more noisy than would be the case with alternative signal formats. The problem would be less severe if it were possible to compensate by increasing the power transmitted by the satellite. Unfortunately, such a solution would be extremely costly to apply.

With present technology, attempts to significantly increase the output power of the travelling-wave tube amplifiers (TWTA) result in increased rates of failure. Moreover, transmission power must be generated from solar-cells, and must be paid for through the increase of weight at launch. A mismatch of ~5 dB might not seem very great, but it implies that the performance of the channel as a whole is limited by the chrominance signal alone, despite the fact that the chrominance bandwidth is only one quarter that of the luminance, and that the chrominance signal-to-noise ratio can be lower than that of the luminance. It follows that, if the chrominance signal-to-noise ratio could be increased by 6 dB, this would produce a reduction in picture noise which would otherwise require an increase in the total satellite power by a factor of four.

In practice, this cannot be achieved with PAL signals due to problems of overdeviation and distortion. Removal of the mismatch might have very significant consequences on the satellite cost, or on the cost of the millions of receiver aerials near the edge of the service area. With the necessary assumptions of the WARC plan many viewers will receive a picture quality little better than grade $3\frac{1}{2}$ unless they use a dish aerial of diameter greater than one metre.

The WARC plan was based on a receiver gain-to-noise-temperature ratio (G/T) of 6 dB/K. Since the date of the plan, receiver technology has improved such that a G/T of 9 dB/K is possible with a one-metre dish aerial. It has been suggested that this improvement will provide the necessary increase in picture quality. However, in the opinion of the IBA, this 3 dB improvement is unlikely to result in an improved video S/N ratio for the domestic viewer. A one-metre dish requires a mounting tolerance of $\pm\frac{1}{2}°$ in order to achieve a gain within 1 dB of the theoretical maximum. While such a tolerance is possible with costly professional equipment, it must be doubtful whether this could be achieved and reasonably maintained for, say, five years in the domestic environment, especially when considering the high wind loading that such a dish must present. In practice, much of this 3 dB improvement will be used to reduce dish size and to simplify mounting. This could also simplify dish steering for reception from other European satellites.

Consider now the question of distortion. Distortion in FM systems arises from two main sources.

(i) Non-linear distortion due to bandwidth limitation.

(ii) Non-linearity in the FM discriminator.

It has already been indicated that high-amplitude high-frequency signals are a major cause of distortion due to overdeviation. Such signals are present in abundance in PAL signals, particularly in high-chrominance areas. Apart from being a cause of distortion, the colour sub-carrier also makes the signal more sensitive to distortion due to the possibility of intermodulation with sound sub-carriers which may be present. Many users have expressed the wish for more than one sound sub-carrier, to allow for stereo or multiple language transmissions. With two or three sub-carriers in the frequency range 4.4–6.5 MHz, the linearity of the satellite channel will have to be closely controlled. A linearity of about 1% must be achieved in the FM channel as a whole (including the home receiver) if unacceptable intermodulation products are to be avoided. Professional-quality receivers currently achieve 1%–3% linearity. Indeed, current proposals for two sound sub-carriers (one digital and one analogue) reduce the video signal-to-noise ratio by 1.5 dB even in such professional-quality receivers.

A further phenomenon of importance in satellite reception is that of the FM threshold effect. This occurs at carrier-to-noise ratios below ~10 dB. Tests have shown this effect to be worsened by the presence of high levels of sub-carrier, and that de-emphasis further increases the subjective impairments of threshold on the TV picture. It is concluded that an improvement to the chrominance signal-to-noise ratio, a decrease in the susceptibility of the signal to non-linear distortions and a reduction in the effects of FM threshold would be advantageous.

A HIGH-RESOLUTION SERVICE?

Since the WARC plan was made in 1977, there has been a growing interest in the possibility of high-resolution television services, capable of display on larger screens. Teams of engineers in a number of laboratories around the world (particularly in Japan

and USA) have been developing experimental equipments for the origination, distribution and display of such signals. The reason for the interest in this field arises from two main sources. Firstly, it is known that pictures viewed at distances of less than 3H (three times picture-height) provide an enhanced experience, by causing the eyes of the viewer to move to take in the whole scene. Until recently, it has been assumed that high-resolution pictures would demand three to four times the bandwidth of existing 525/625-line services; but only broadcast systems are essentially limited in bandwidth (due to increasing demands on the radio frequency spectrum). Home video systems are limited in bandwidth through technology alone, which continues to develop with increasing pace. It is possible that, by the end of the century, the home viewer will have a choice between several picture sources, broadcast television providing the lowest quality. This would not be of particular concern if it were foreseeable that broadcasters could employ new areas of the radio spectrum to provide high-resolution transmissions. But, in Europe at least, all the useful frequencies up to 40 GHz have been allocated to non-broadcast services apart from the direct-broadcast allocation in the 12 GHz band.

Transmissions in the 40 GHz region would not be very suited to television applications, due to their sensitivity to local weather conditions, particularly rain. For the 40 GHz band, it will be necessary to limit the diameter of the receiving aerial to 50 cm if pointing accuracies better than $\pm\frac{1}{4}^{\circ}$ are to be avoided. Assuming national coverage, and allowing a reasonable margin for fading during rainfall, this limitation implies a minimum satellite power of about 10 kW. The technology to achieve this will not be available for many years to come. *Direct-broadcast transmissions in the 12 GHz band may be the last chance for broadcasters in Europe to provide a service with the potential for large-screen display.*

However, most European broadcasters would be attracted to an improved resolution service by satellite only if the signals could be displayed on existing sets without a significant cost penalty to small-screen viewers.

The only reasonable prospect for an improved-resolution broadcast television service in Europe is to make use of the 12 GHz WARC channels, and with a signal which can also be displayed through an interface to existing receivers. The direct-broadcast channels are seen by many public service broadcasters as a way in which television can be brought to the small percentage of viewers unserved by existing terrestrial transmitters. It is essential that these viewers should not be burdened with additional cost as a result of using a signal which has the potential for large-screen viewing.

It has been suggested that an all-digital broadcast signal might provide the optimum solution for the WARC channel. However, estimates for the capacity of the WARC channel vary in the range 15–35 Mbit/s, and (optimistically) an extended-definition picture (using frame-store bit-rate reduction methods) would require 100 Mbit/s. Research work in progress will probably lead to significant reduction of this figure but the techniques involved offer no low-cost option for the small-screen viewer. Therefore, the digital solution must be excluded due to the risk that the technology will not exist within the time-scale envisaged for the new services. These constraints on the design of an improved-definition television system create an interest in looking for areas of inefficiency in the FM PAL signal.

The following impairments can be seen when conventionally displayed PAL signals are viewed at a distance of 3 H:

Cross-colour
Cross-luminance
Large-area flicker
Temporal aliasing
Vertical aliasing
Lack of vertical resolution
Lack of horizontal resolution.

Cross-colour and cross-luminance may be excluded by using a separate-component transmission system. Alternative methods are available; but in general, these make almost impossible the elimination of some of the other impairments on the list.

Large-area flicker is a peripheral vision effect which is a function not merely of the signal, but also of the display device. It may be removed by displaying each frame twice within a single frame period or, more efficiently, by using a screen which continues to display information until refreshed.

Temporal aliasing is the effect which causes wagon wheels to appear to go backwards. Increasing the frame-rate will not reduce the effect, it will merely change the frequency at which it occurs. The right approach is to remove high temporal frequencies prior to display. There is no evidence to suppose that the temporal resolution afforded by the 50 Hz field-rate is insufficient.

Vertical aliasing (visibility of line-structure) is perhaps the worst defect in high-quality YUV signals displayed in the conventional 625-line interlace

format. Again, it is the result of inadequate filtering rather than insufficient resolution.

This leaves the question of whether the vertical and horizontal resolution in 625-line YUV signals is sufficient to allow large-screen display. In the case of vertical resolution, distinction must be made between transmission format and the display format. For example, it is found that a 625-line 2 : 1 interlace display is capable of only $156\frac{1}{4}$ cycles/picture height of alias free resolution, but that a 625-line sequential display (625-lines/field) is capable of $312\frac{1}{2}$ cycles/picture height even when the signals are derived from a conventional 2 : 1 interlace signal. An improvement in horizontal resolution would follow from an increase in channel bandwidth, although this would not be possible with the WARC direct-broadcast channel due to considerations of interface and/or noise. However, alternative methods for increasing horizontal resolution are available, the basis of which will now be described.

The PAL signal is an inefficient user of spectrum space. Firstly, there is an obvious inefficiency in that 24% of the signal is absorbed in sending blanking periods rather than useful picture information. The field-blanking period (8%) is rather difficult to exploit, but the line-blanking periods (16%) could be used to improve picture quality. A second cause of inefficiency arises due to the repetitive nature of the signal. Most lines of a television picture are very similar to those adjacent, and a repetitive signal of this type produces a line-spectrum in the frequency domain. In fact, because there are usually small differences between adjacent television lines, the energy falls, not on discrete frequencies, but in a series of narrow packets occurring at regular intervals along the frequency axis.

The interval between packets is precisely equal to the repetition frequency of the signal, namely the television line frequency of 15.625 KHz. The spectral occupancy, therefore, varies in a predictable way, with much of the spectrum (between the packets) carrying little useful information.

The photographs of Fig. 3 show the poor spectral occupancy achieved by composite signals. This property may be exploited to provide improved horizontal resolution without increasing the transmission bandwidth.

An ideal signal for direct broadcasts by satellite would have the following characteristics. It would be analogue, and compatible with display on a conventional 2 : 1 interlace 625-line receiver through a suitable interface. It would avoid the use of a high-frequency colour sub-carrier which introduces problems of cross-colour, cross-luminance and susceptibility to FM noise and distortion. It would provide increase of resolution by avoiding the spectral inefficiency of conventional composite signals. It would allow for the removal of vertical and temporal aliasing in the receiver by those willing to pay for the necessary processing in the receiver. A signal of this

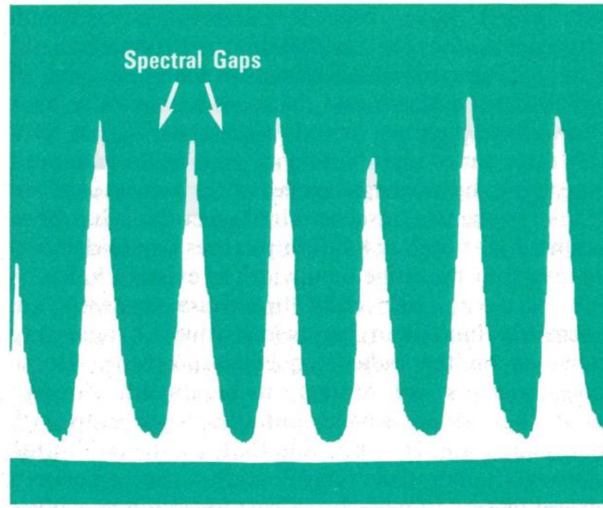


Fig. (3a). The luminance spectrum for conventional TV signals. The available spectrum is not used efficiently.

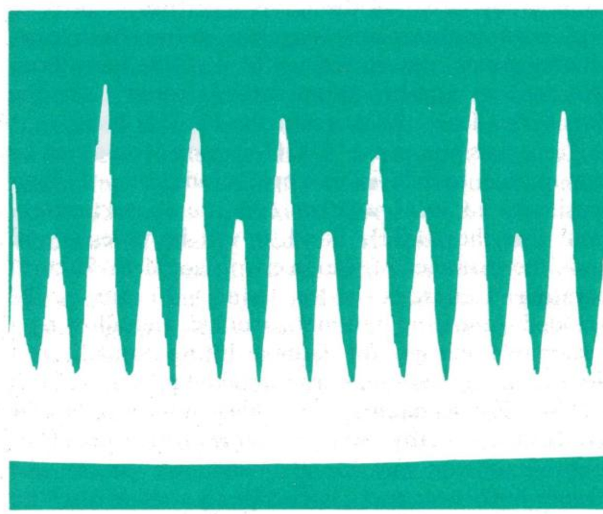


Fig. 3(b). The improved efficiency of spectrum utilisation when 2-D processing is employed.

These spectra were obtained under the following conditions: Material—SMPTE Alignment and Resolution Slide, Scan Centre—4 MHz, Horizontal Scale—10 KHz/Div, Vertical Scale—Linear, Analysis Bandwidth—3 KHz.

type would provide an extended-definition television service to the public without incurring additional costs for those who do not wish to use the extended-definition facility. The following paragraphs describe a signal with many of these properties.

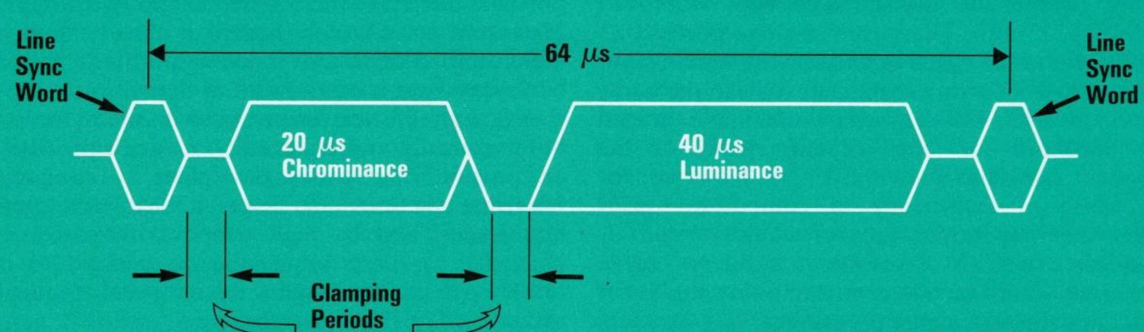
MULTIPLEXED ANALOGUE COMPONENT (MAC) SIGNALS

From the foregoing discussion it will be clear that it should not be difficult to devise a signal which will greatly improve on the quality of PAL in an FM channel. One method will be described below, and variants of the scheme will be discussed in the remainder of this chapter.

PAL signals normally achieve about 3.8 MHz of useful luminance bandwidth, higher frequencies being impaired by cross-luminance effects in typical decoders. A 'clean' luminance bandwidth of 4.5 MHz will be assumed as a figure which would represent an improvement (or at least comparability) with the performance of PAL. Similarly, a figure of 1.3 MHz will be assumed for the colour-difference channels, with a vertical resolution equal to half that of the luminance channel.

If each line of the luminance signal is compressed in time from 52 μs to 40 μs, the transmission bandwidth increases proportionally. A luminance signal limited to a bandwidth of 4.5 MHz would then pass through a 5.85 MHz channel in this time-compressed form. At least 20 μs of the line would be available for the colour-difference signals, allowing a sequential colour-difference transmission of 2.2 MHz bandwidth (Fig. 4). Filtering to 1.3 MHz bandwidth would be applied in the receiver to improve signal-to-noise ratio.

For a signal with this format, calculations show that the weighted signal-to-noise ratio in the colour channels would be improved by 5 dB in comparison with pre-emphasised PAL (the luminance signal-to-noise ratio being virtually unchanged) (Appendix). In addition, cross-colour, cross-luminance, and the effect of truncating the upper chrominance sideband would be eliminated. Moreover, the calculation takes no account of the fact that the new signal has no high-frequency sub-carrier, and is less sensitive to distortion. Therefore, the inefficiency caused by the mismatch between the PAL signal and the FM noise spectrum, together with the existence of the line-



Weighted Signal/Noise Ratios

	Luminance (4.5MHz Bandwidth)	Colour Difference (1.3MHz Bandwidth)
PAL (with pre-emphasis)	∼44dB	∼35dB
MAC	∼44dB	∼40dB

Fig. 4. A Multiplexed Analogue Component (MAC) signal.

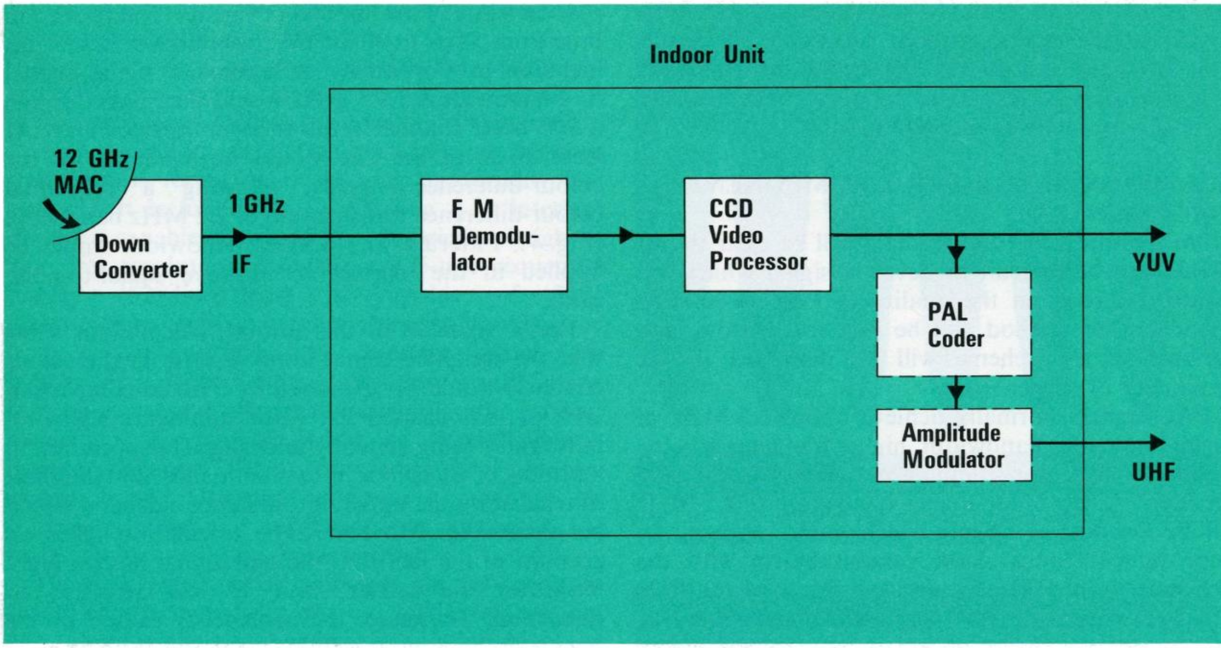


Fig. 5. A MAC Satellite Converter.

blanking period, provides sufficient margin to allow a separate component transmission with improved signal-to-noise ratio. These factors alone portend an improvement in the signal quality for the small-screen viewer without incurring significant costs in the home satellite converter. The converter would then require a CCD line-store for time decompression of the component signals as shown in Fig. 5. However, the main cause of inefficiency in composite signals (namely their repetitious nature) would remain. A compatible extension of resolution for large-screen applications would be based on exploiting this latter redundancy through signal processing.

Extended Definition Through Signal Processing

The analogue television signal represents a dynamic scene which has been sampled in two dimensions; i.e. it has been sampled vertically by the line structure, and temporally by the field structure. Any sampling process generates spurious spectral components which can give rise to aliasing–impairment of the baseband spectrum through intermodulation with the sampling frequency. A frequency f produces an intermodulation component $(fs-f)$ where fs is the sampling frequency. This gives rise to a repeat of the baseband spectrum centred on the sample frequency fs.

To avoid aliasing, the baseband spectrum must be low-pass filtered to remove frequencies exceeding $fs/2$. Moreover, a similar low-pass filter must be used after digital-to-analogue conversion so that only the baseband spectrum is reproduced at the output.

Although the television signal samples the scene both vertically and temporally, no such pre-filtering or post-filtering has taken place. Consequently, television pictures are impaired by high vertical frequencies, and by high temporal frequencies. In particular, vertical frequencies exceeding $156\frac{1}{4}$ c/ph (cycles per picture height), or temporal frequencies exceeding $12\frac{1}{2}$ Hz, cause aliasing.

To remove these impairments, it is necessary to introduce a vertical/temporal pre-filter and post-filter. Only when the necessary characteristics of these filters are considered does the potential for increasing the vertical and temporal resolution become evident.

The line-interlace structure, considered as a sample frequency, must be treated in two dimensions. The lines sample the scene vertically, but are also displaced along the temporal axis (i.e. between adjacent fields). Therefore one must introduce the concept of a two-dimensional frequency plane as shown in Fig. 6. The interlaced line structure is represented by a point in this plane at $312\frac{1}{2}$ c/ph, and 25 Hz temporal frequency.

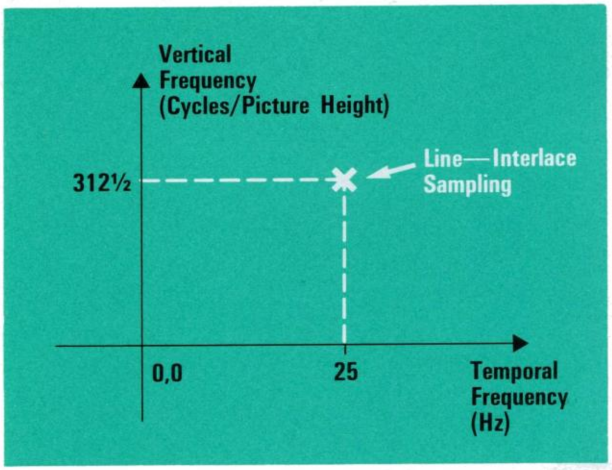


Fig. 6. A two-dimensional frequency diagram, showing the equivalent sampling frequencies for a line-interlaced scan.

The baseband signal is centred on the point (0, 0) and is unrestricted in extent, except by the sampling aperture (that is, the spot-size and persistence), there being no pre-filter either vertically or temporally. As in the one-dimensional case, the effect of the sampling process is of introducing a repeat baseband spectrum on the site of the sampling frequency. Clearly, unless pre-filtering is applied, vertical frequencies exceeding $156\frac{1}{4}$ c/ph and temporal frequencies exceeding $12\frac{1}{2}$ Hz enter the baseband region. Even if suitable pre-filtering is employed, the repeat spectrum will be apparent in the display unless post-filtering also is applied—this is merely the visibility of line-structure familiar in all television pictures. The simplest arrangement for the removal of vertical and temporal aliasing would be to introduce separate filters in the vertical and temporal directions, as shown in Fig. 7.

This would avoid the aliasing which arises from overlap between the baseband and repeat spectra. However, half the frequency space would then be wasted. Therefore, it is possible to double either the vertical or the temporal resolution without causing aliasing. Alternatively, a combined vertical/temporal filter can produce a peak resolution of $312\frac{1}{2}$ c/ph and 25 Hz. This characteristic approximates that of the human eye which can, only in static scenes, perceive high spatial resolution. It is clear that, though a conventional line-interlace structure ($312\frac{1}{2}$ lines/field) can support a vertical resolution of $312\frac{1}{2}$ c/ph, it does not do so if the scene is sampled directly with line-interlace scanning. Aliasing into the baseband region occurs during the scanning process and cannot be removed by subsequent filtering. Consequently, it is necessary to provide an initial scan which contains more lines (for example, by doubling their number to 625-lines per field) so that aliasing into the baseband region is essentially avoided. This signal can then be pre-filtered (vertically and temporally) to remove those frequencies which cannot be carried by the $312\frac{1}{2}$-line interlace signal. Alternate lines are then discarded to produce the conventional interlace signal, which then carries enhanced vertical/temporal resolution (without aliasing) as indicated in Fig. 7.

This signal could be displayed on a conventional interlace monitor, which would then show improved aliasing characteristics. The line structure would remain visible however, due to the presence of the repeat spectrum at $312\frac{1}{2}$ c/ph/25 Hz. The full potential of the signal can be realised only if a post-filter is included prior to the display. The repeat spectrum is unavoidable in a $312\frac{1}{2}$-line interlace display, but the post-filter has the effect of interpolating the lines which were originally dropped, and so as to recreate the 625-lines/field signal. Indeed, it can be shown that the functions of post-filtering and line interpolation are mathematically equivalent[3]. The procedure just described above provides a transmission signal which may be viewed, either on a conventional display, or with enhanced resolution by including the necessary filtering. *It therefore represents a compatible extension to resolution, the costs of which are borne only by those users who wish to pay for the improved picture quality.* It cannot simply be applied to composite signals, because the post-filtering operation destroys the sub-carrier phase relationships. It can, however, be applied separately to each component of a YUV transmission.

The compatible enhancement of vertical resolution arose through an optimisation of the filters associated with the vertical sampling (scanning) of the scene. It is interesting to consider whether a similar enhancement can be achieved in the horizontal direction, by deliberately introducing a horizontal sampling process where none is otherwise necessary. This question has been considered in some detail[3], and it is found that an improved horizontal bandwidth can be achieved through a similar technique.

Suppose that a luminance signal is sampled at a frequency of, say, 9 MHz, using the 'field-quincunx' sample structure of Fig. 8: this sample structure must be analysed in three dimensions, the samples being displaced horizontally, vertically and temporally. Consequently, the repeat spectra generated by the sample structure occur in three-dimensional frequency space.

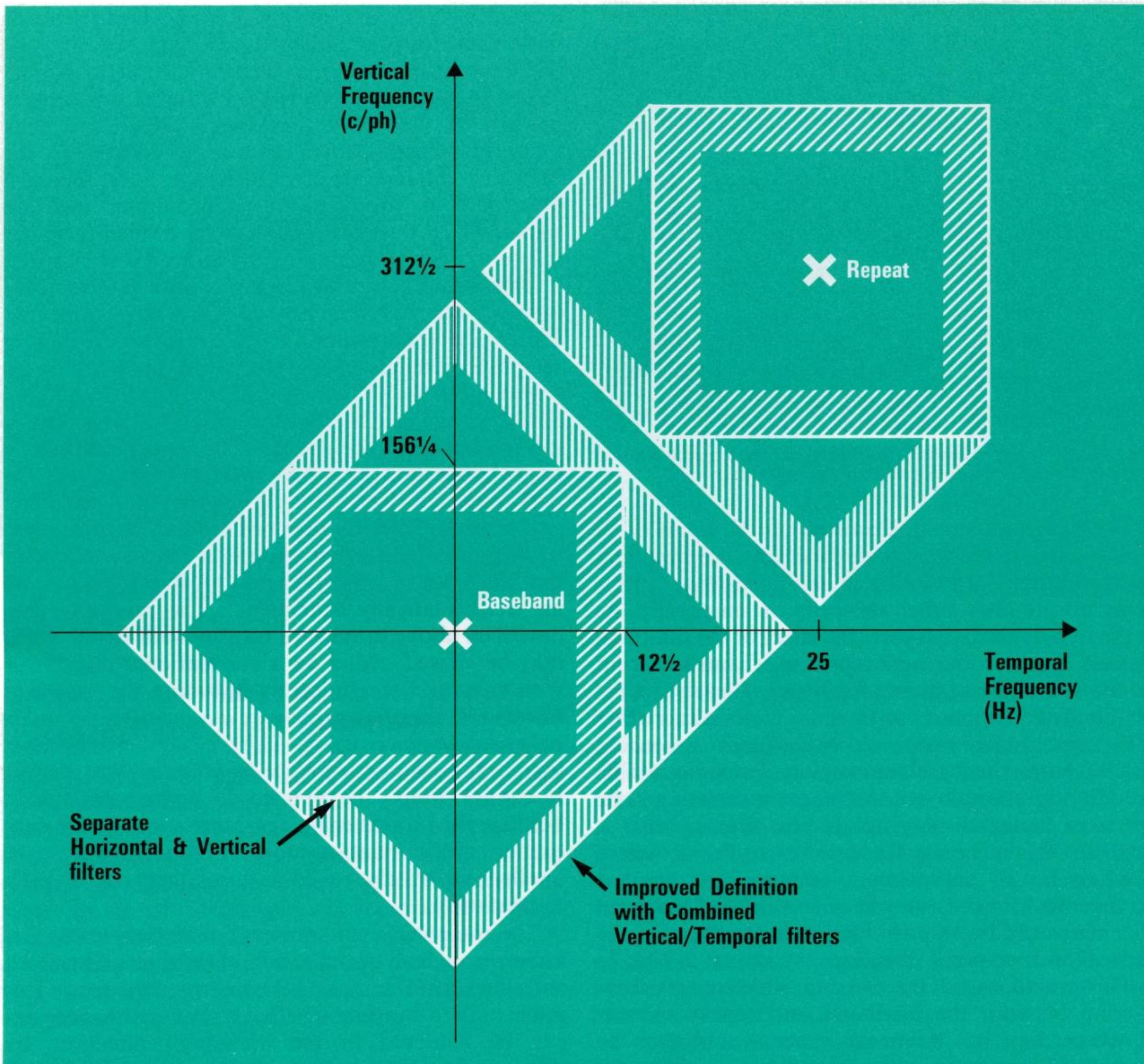


Fig. 7. The alias-free zones with separate vertical and temporal filters (inclined hatching), and with combined vertical/temporal filters providing improved definition (vertical hatching).

Suitable three-dimensional filtering can (in principle) then create an alias free (unity gain) region extending to 9 MHz horizontally, $312\frac{1}{2}$ c/ph vertically and 25 Hz temporally, as shown in Fig. 9. As in the two-dimensional case, the source coding must be a 625-lines/field sequential scan signal, with alternate lines dropped after the pre-filtering process, thereby creating a compatible field-interlace structure. The extended-definition receiver would include a similar post-filter/interpolator prior to a 625-line sequential display. When one considers that a PAL transmission typically achieves only 4 MHz of horizontal resolution, a little over $156\frac{1}{4}$ c/ph vertically and $12\frac{1}{2}$ Hz temporally, and is impaired by aliasing, cross-colour and cross-luminance, there can be little doubt that separate component signals as defined in Fig. 8 would be capable of large-screen display. In principle, impulses at 9 MHz rate can pass through an analogue

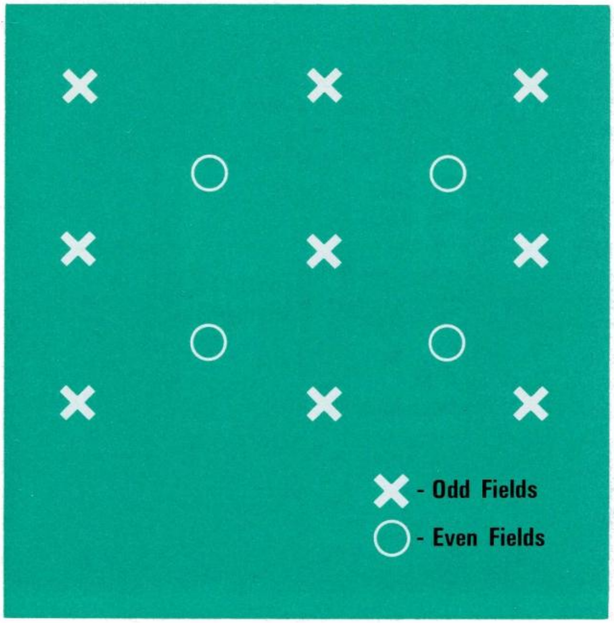


Fig. 8. A field-quincunx sample structure.

Nyquist channel of 4.5 MHz bandwidth without impairment, or through a 5.85 MHz channel when time compressed from 52 μs to 40 μs per line. It is less than obvious that the technique also improves the spectral efficiency of the signal; or, indeed, that the extended definition arises directly as a result of this improvement. It has already been indicated that conventional signals contain a series of gaps in the spectrum which carry only high-frequency diagonal information. When high-frequency diagonals are excluded, as in Fig. 9, these gaps become available to carry more useful information. The effect of the 3-D sampling process described is deliberately to alias useful high-frequency information into these gaps. The original spectrum can then be truncated, in the knowledge that high frequencies are carried elsewhere in the signal. The advantage is illustrated in the case of two-dimensional processing by the spectrum shown in Fig. 3b. The post-filter/interpolator restores the folded energy to its rightful position at high frequency, thereby recreating the original spectrum. It follows that, when such signals are viewed directly on a conventional line-interlace display (without the 3-D post-filter), an alias product is present on high-frequency gratings. However, experiments made with an unfiltered field-quincunx structure suggest that the impairment for the small-screen viewer should be significantly less disturbing than is cross-colour in the PAL signal.

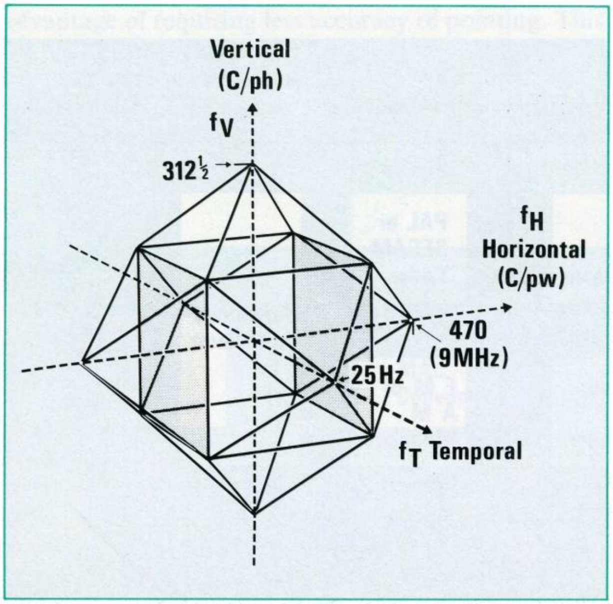


Fig. 9. The spatio-temporal resolution provided by 3-dimensional signal processing.

Techniques similar to those described above could be separately applied to the colour-difference channels. Investigation work is in progress to optimise the balance between the resolution achieved in the three component channels, taking account of the receiver complexity.

Receiver Implications

The simplest conception of a direct-broadcast converter (using FM composite modulation) is as shown in Fig. 1. However, the desire for multiple sound channels has upset this simple scheme, and various options which include additional sub-carriers are under consideration. Since there is a demand for commentary channels in several different languages, it has been necessary to consider systems which allow a maximum of six sound channels. It is not feasible to introduce a separate sub-carrier for each of these channels, and a proposal for a single digital sub-carrier for multiplexed sound and data therefore appears to offer the least costly solution. For this reason, the scheme of Fig. 1 must be abandoned, and a basic receiver would become more complex. The addition of multi-channel digital sound is unlikely to increase costs significantly, because the necessary circuitry can be minimised through large-scale integration. However, the further additions necessary

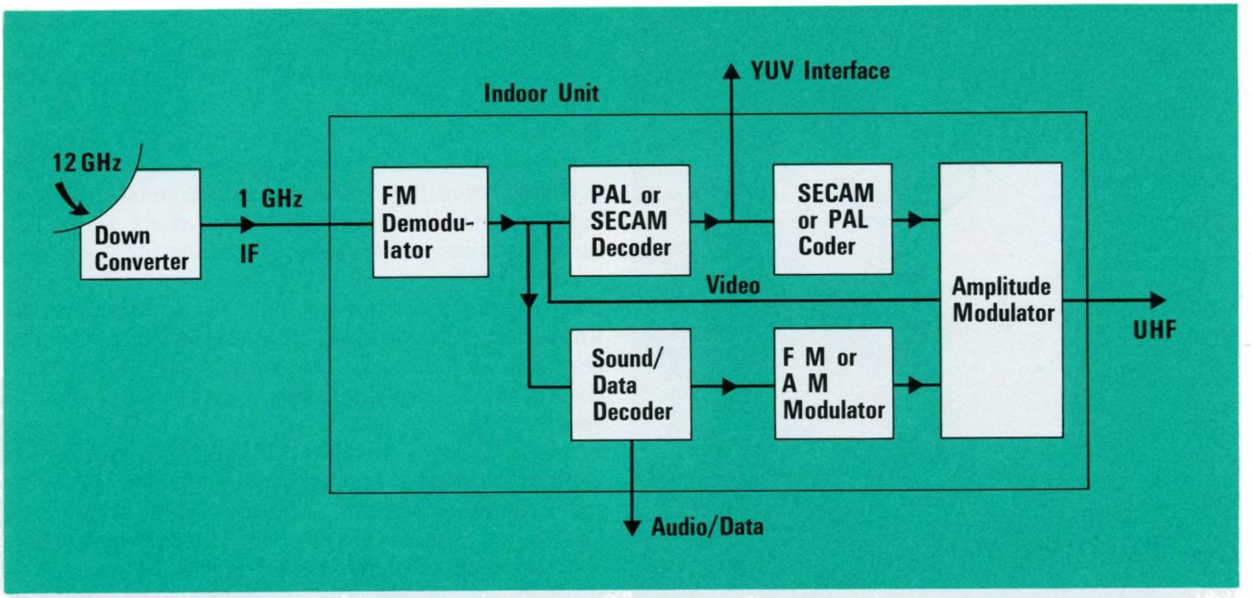


Fig. 10. A multi-standard satellite converter with digital-sound decoder.

for those wishing to receive several incompatible national broadcasts require a more elaborate and more costly receiver as shown in Fig. 10.

The receiver for a Multiple Analogue Component (MAC) transmission would include circuits for baseband video processing and for encoding the signal into composite form (Fig. 11a). Both these operations (including a video decompression line-store using CCDs) employ known technology and are amenable to large-scale integration. Composite encoders already exist as single integrated components. Therefore, the additional costs involved are unlikely to be great. Some of these cost increases can be offset by factors affording cost savings. Firstly,

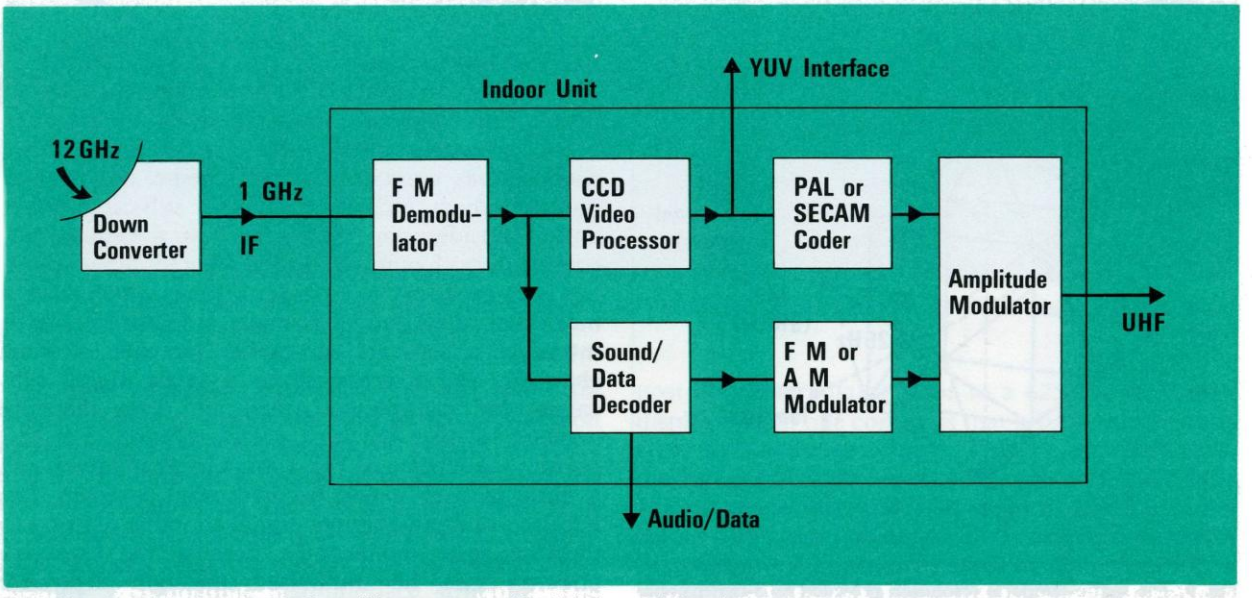


Fig. 11(a). A multi-standard MAC satellite converter with digital sound decoder.

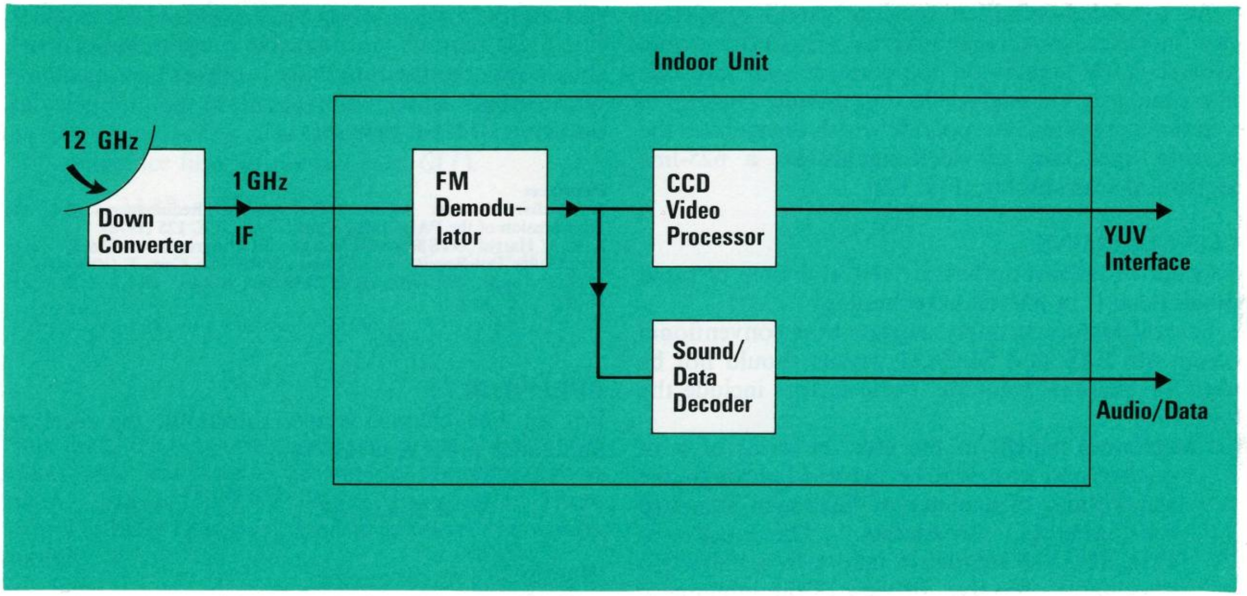


Fig. 11 (b). A universal MAC converter with a single-standard YUV output.

the improved S/N ratio in the chrominance channel should, in many locations, allow use of a smaller dish aerial. These locations will include all sites with sufficient protection ratio from adjacent satellites. Apart from being more acceptable from the environmental viewpoint, smaller dishes have the advantage of requiring less accuracy of pointing. This could be important for installations designed to capture the services of several satellites. Cost reductions will also occur on the periphery of the service area (or indeed beyond it) where increase of the dish size beyond one metre will be avoided.

Secondly, where a baseband component interface to an existing receiver is employed, several circuits in the converter may be eliminated. These will include the composite encoder, the FM sound modulator and UHF modulator. The universal satellite converter is then as shown in Fig. 11b. As well as providing higher quality, this receiver configuration would certainly be less expensive than the one currently proposed. Note should be taken that baseband component interfaces are now fitted to all new receivers in France and Germany, so that long-term cost reductions would be inevitable.

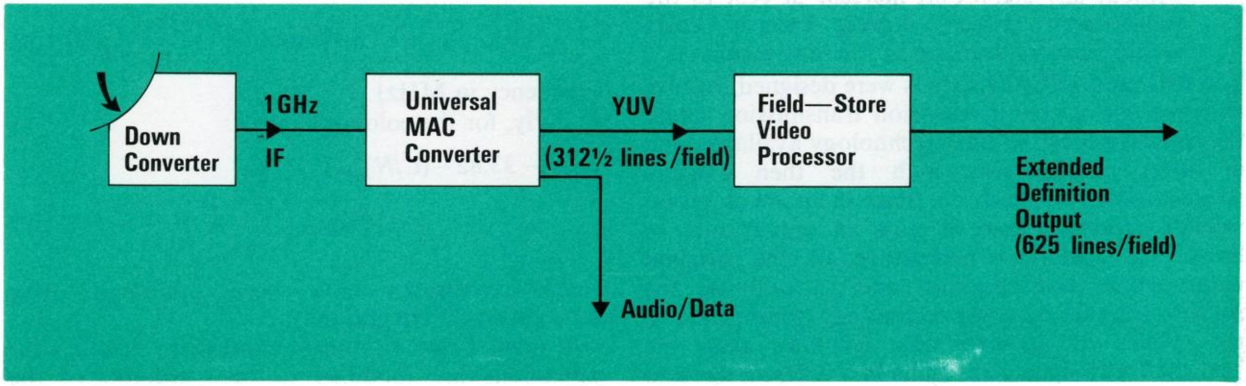


Fig. 12. A MAC converter providing an extended definition output.

An extended-definition receiver would consist of two modules. A down-converter (Fig. 11b) would provide YUV signals on the conventional interlace line-standard. The high-definition module consists of a frame-store filter/interpolator which regenerates the missing lines and provides signals for a 625-line sequential-scan display (Fig. 12).

CONCLUSIONS

Satellite Broadcasting has arrived at a time of rapid developments in television technology.

Several factors strongly suggest that conventional composite PAL and SECAM signals should not be used for this new medium. These factors include the following:

(*a*) Maximum benefit to the user, in terms of both quality and cost will be achieved through the establishing of a common European standard for satellite broadcasts. The use of PAL/SECAM signifies a failure to achieve this reasonable objective. In view of the imminence of an international studio standard based on separate-component signals, and on the development of separate-component interfaces to domestic receivers, this form of modulation could be adopted throughout Europe and possibly world-wide.

(*b*) PAL and SECAM signals are poorly matched to the characteristics of the FM broadcast channel, and result in levels of chrominance noise which are unnecessarily high. Forms of separate component transmission (in particular, Multiplexed Analogue Components) remove this problem, eliminate cross-colour, cross-luminance and U/V crosstalk, and make possible an extended-definition service for the future. These advantages could be achieved without any significant increase in cost to the small-screen viewer; indeed, receiver costs would actually decrease in the long term.

The PAL and SECAM signals were designed to solve the problem of colour television transmission under the constraints of the early technology available, and of strict compatibility with the then existing monochrome AM receivers. Since there are as yet no satellite receivers, there is now an opportunity to break the historical precedence of the original monochrome transmissions, and to optimise the satellite channel by using technology appropriate to the 1980s. It is extremely unlikely that the PAL/SECAM signals (designed in a different age and for a different application) would compare in quality with modern alternatives for broadcasts by satellite. For these reasons, an intensive programme of work should be organised urgently to identify an optimum direct-broadcast television standard without delaying the onset of these new services.

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APPENDIX

For an FM channel above threshold, the received luminance noise is given by:

$$N_Y = 10 \log_{10} K \int_0^{f_{\max}} \frac{W(f)}{E(f)} f^2 \, df$$

Where:

$W(f)$ is the noise weighting characteristic established through subjective testing (CCIR Rec. 451–2).

$E(f)$ is the pre-emphasis characteristic defined according to CCIR Rec. 405–1 as follows:

$$E(f) = \frac{A(1+Cf^2)}{(1+Bf^2)} \qquad A = 0.0794, \quad B = 0.4083, \quad C = 10.21$$

K is a constant appropriate to the bandwidth, deviation and carrier-to-noise ratio (C/N) of the WARC channel.

This leads to the following result, which has been confirmed experimentally:

$$N_Y = -33.82 - (C/N)_{\mathrm{dB}} + 10 \log_{10}\left(\int_0^{f_{\max}} \frac{W(f)}{E(f)} f^2 df\right) \mathrm{dB}$$

(Frequency in MHz)

Similarly, for the colour channels:

$$N_C = -33.82 - (C/N)_{\mathrm{dB}} + 10 \log_{10}\left(\int_0^{f_{\max}} \frac{W(f-fc)}{E(f)} f^2 df\right) \mathrm{dB}$$

These expressions have been evaluated using Simpson's rule integration.

In the case of time-compressed signals, the expressions are modified to take account of the following:

(1) Baseband transmission of colour-difference signals.
(2) Time-compression of both luminance and chrominance by factors of x_y and x_c respectively.
(3) The introduction of a Gaussian 1.3 MHz colour-difference filter in the receiver, $G(f)$.

$$N'_y = -33.82 - (C/N)_{\mathrm{dB}} + 10\log_{10}\left(\int_0^{f_{\max}} \frac{W(f/x_y)}{E(f)} f^2 df\right)$$

$$N'_c = N'_u + N'_v = -33.82 - (C/N)_{\mathrm{dB}} + 10\log_{10}\left(2\int_0^{f_{\max}} \frac{W(f/x_c)}{E(f)} f^2 df\right)$$

Note that, to a first-order approximation, the received noise power increases as the cube of the compression factor [since $\int p(f/x) f^2 df = x^3 \int P(q) q^2 dq$]. These formulae have been evaluated to produce the results quoted.

Propagation Tests

by H. J. O'Neill and D. Hayter

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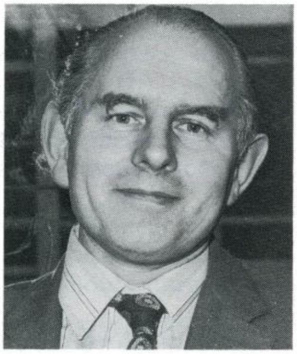
His present post is Head of Frequency Planning Unit in the same section with particular responsibility for the planning of Independent Local Radio and Television Services. He is a member of BSI committee GEL 111 and in addition a member of EBU sub-committee R6. He is married with two sons and lives in Hampshire.



Synopsis

This article presents the results of propagation experiments made at Crawley Court during the first two years service of the Orbital Test Satellite (OTS).

The experiments used beacon transmitters on the satellite operating at constant level. Variations in the levels of the received signals were used as measurements of atmospheric attenuation and depolarisation. Results for both circular and linear polarisation have been obtained.

The World Broadcasting Satellite Administrative Radio Conference for Regions 1 and 3 held in Geneva in 1977 formulated plans for direct broadcast satellite services. The band 11.7–12.5 GHz was allocated for Region 1 and 11.7–12.2 GHz for Region 3.

At the Conference it was agreed to plan the service on the basis of a particular power flux density at the edge of each service area, after allowing a margin for atmospheric attenuation of the signal.

One of the purposes of the propagation tests at Crawley Court was to confirm the statistical relationship between atmospheric attenuation and time. A second purpose of the tests was to confirm the

feasibility of frequency re-use by orthogonal polarisation, which is to be a feature of future communication satellite systems. Also, information on specific and statistical characteristics of individual atmospheric fade events was required. This chapter presents the results of propagation experiments made at Crawley Court over the first two years service of OTS. The experiments used beacon transmitters on the satellite operating at constant level. The variations in the received signal levels were used to study atmospheric attenuation and depolarisation. Results for both circular and linear polarisation have been obtained.

CHARACTERISTICS OF OTS BEACON SIGNALS

Circularly Polarised Beacons

Co-polar signals from the right hand (B0) and left hand (B1) circularly polarised beacons were found to vary with time in both frequency and amplitude. The cross-polar components of these signals also varied. The frequency variations were of both a short-term (diurnal) and long-term (seasonal) nature. The diurnal variations were about ± 12 kHz per day. The long-term variations were random but were within the specified value of ± 350 kHz. The amplitude of the signals varied by about 1.5 dB over a typical 24 hour period, and the level of the cross-polar components varied between -28 and -30 dB over a typical 24 hour period. There was a long-term decline in the co-polar amplitude of both the B0 and B1 beacons of several dB.

During eclipses, variations in frequency, amplitude and cross-polar components of the same magnitude occurred suggesting that the causes of the diurnal changes were temperature effects in the satellite. Figure 1 is a plot of typical frequency and amplitude variations of the B0 beacon over a 24-hour period showing the effect of an eclipse.

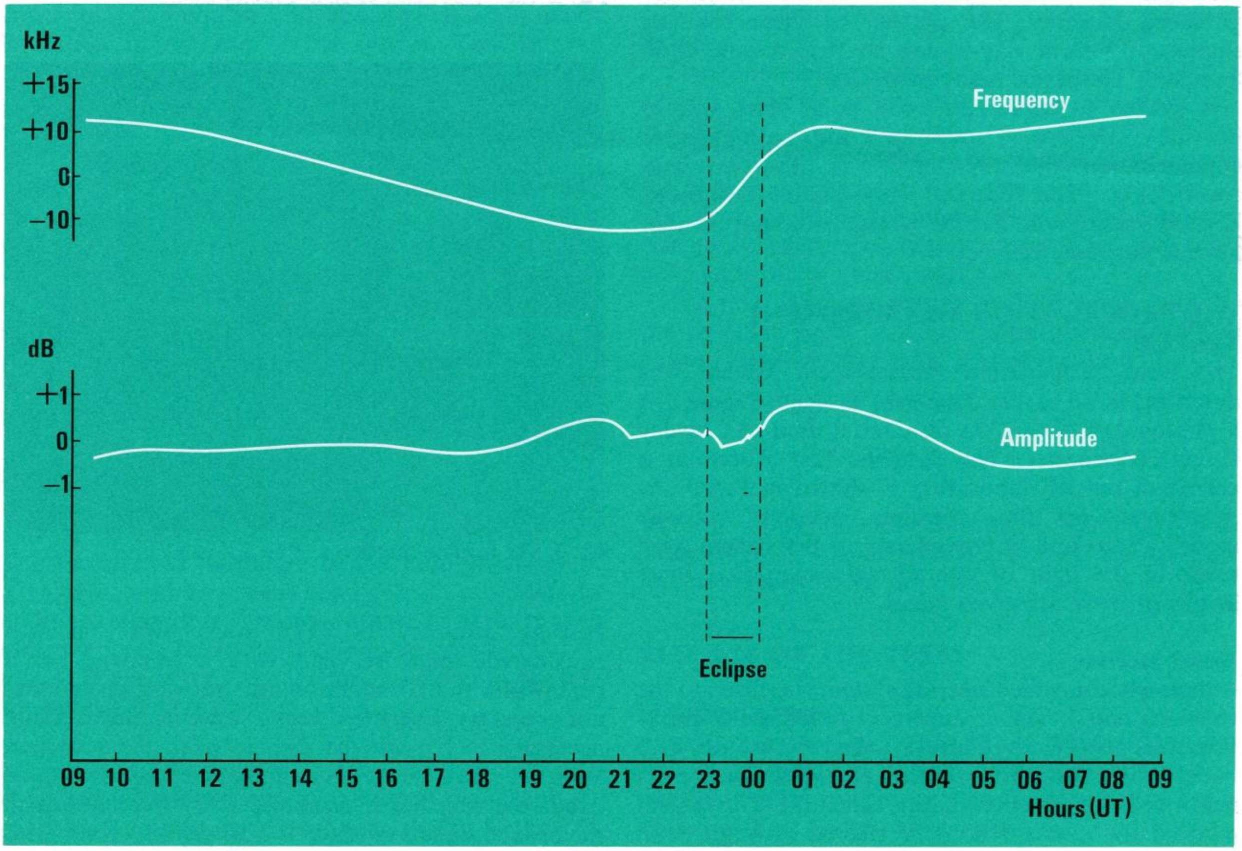


Fig. 1. Diurnal variations of the OTS Beacon B0 on 7–8th March 1979.

Linearly Polarised Beacon

The frequency stability of the telemetry beacon (TM) was very good, diurnal changes were less than 1 kHz per day and long-term changes were within 10 kHz.

Diurnal amplitude variation was better than 0.5 dB and cross-polar level consistently more than 35 dB below co-polar level. However, ranging pulses affected the level of the beacon. These occurred every few hours and caused a decrease of 0.5 dB in the signal lasting about six minutes.

Implication of Beacon Variations on Accuracy of Propagation Measurements

The ideal source for propagation measurements would be of constant frequency and amplitude with good cross-polar isolation. The variations experienced (particularly in the B0 and B1 beacons) were inconvenient and in some cases special modifications to the receiver were necessary to make accurate propagation measurements possible. The most inconvenient characteristic to deal with was the variation of cross-polar level of the circularly polarised beacons. The pattern of these changed significantly from day-to-day so that a correction 'template' could not easily be derived.

A system to cancel the cross-polar level and so provide a low threshold for atmospheric depolarisation measurements was designed and constructed. The beacon cross-polar variations, however, were such that the system could not be used for this purpose. (See below.)

Fig. 2. The 3-metre dish aerial at Crawley Court.

Fig. 3. The Satellite Test Room in the RF Laboratory.

THE PROPAGATION MEASUREMENT SYSTEM

The basic propagation measurement system was described in an earlier *Technical Review*[1]. Figure 2 is a photograph of the 3 m dish aerial used at Crawley Court, Winchester. The Satellite Test Room in a corner of the RF laboratory is shown in Fig. 3. As mentioned in the previous section, various modifications and improvements to the system were made in the light of operational experience. Brief details of these are given below.

Aerial Steering

A remotely controlled steering system was fitted to the receiving aerial. The arrangement made use of linear actuators operated by constant speed a.c. motors with linear potentiometers to provide an indication of aerial position in azimuth and elevation. The system enabled the dish aerial to be steered through 5° in each axis with an accuracy of $\pm 0.01°$. The station keeping accuracy of OTS was $\pm 0.1°$; it was considered, therefore, that with a receiving aerial beamwidth of 0.5° an automatic tracking system was not necessary. Every few weeks, however, it was found necessary to repoint the dish to peak the response. With the signal peaked, satellite movement within the fixed receiving beam produced daily fluctuations in the beacon signals of about 0.2 dB peak-to-peak. This was considered negligible.

Cancellation System
The cross-polar discrimination of the OTS 'Eurobeam B' aerials transmitting the circularly polarised signals was specified to be 28 dB and that of the Crawley Court aerial to be 35 dB.

To permit accurate measurements of atmospheric depolarisation down to 35 dB (below co-polar) a system to cancel the cross-polar coupling caused by the aerials is needed. Such a system was designed and constructed. The method consisted of cross-coupling a fraction of the signal in the co-polar channel into the input of the cross-polar channel at an appropriate amplitude and phase so as to cancel the unwanted co-polar component. The system is adjusted in clear weather conditions when only the transmitting and receiving systems should introduce a cross-polar component. Motor-controlled microwave attenuator and phase shifter units, installed at the rear of the dish aerial and operated from the laboratory, were used. The arrangement was capable of cancelling unwanted cross-polar components down to 50 dB below the co-polar component. However, the constantly changing cross-polar component from the satellite was a major limitation in the use of the system. This varying component—which was unforeseen—produced a measurement threshold in the cross-polar channel which could, within 24 hours, change from 50 dB to 30 dB below co-polar even when the cancellation system was used. Since the day-to-day pattern was variable, no programmed change in the cancellation system settings was feasible. Instead of being used for fixed cancellation, therefore, the system was employed for making accurate spot measurements of cross-polar levels at particular times of day and during the preceding eclipses. This information was forwarded to The European Space Agency (ESA) to facilitate their investigation into the cause of the changes.

Hold-in Range on the Receiver
As previously mentioned, the frequency of both the B0 and B1 beacons varied by about ± 12 kHz per day. The receiver, as delivered, had a hold-on range of ± 15 kHz; and so, occasionally, lock was lost. In addition, amplitude variations appeared at the output (when in lock) due to the bandpass response of the IF filters. The receiver was therefore modified to provide the necessary performance.

Reception of TM Beacon
Owing to the relatively poor stability of the B0 and B1 beacons, it was decided to tune the system to the TM beacon. A local oscillator frequency synthesiser and mixer stage were therefore added at the IF stage. The auto-calibration function within the system was maintained by, every two hours, switching the system automatically to the frequency required for calibration.

It was necessary to provide a bandpass microwave filter tuned to the TM frequency to remove interference arising from television signals in the Channel 4 transponder of the satellite.

Data Collection and Processing
In February 1979 monitoring of the B0/B1 circularly polarised beacon transmissions commenced; but, some delays were experienced due to the need for modifications in the receiver. However, about six months data for circular polarisation were then obtained.

In March 1980, the decision was taken to monitor the linearly polarised telemetry (TM) beacon transmission at a frequency of 11.575 GHz. The advantage of using this beacon was the superior frequency and amplitude stability of its output as compared with those of the circularly polarised beacons.

Data obtained from the co-polar channel of the TM beacon receiver over several days of clear sky conditions was examined to determine the practicability of modelling the diurnal variations in the level of this signal. If this were found to be so, all raw data could be examined in a single computer operation, and event data could be extracted independently of these variations.

The final template model, evolved empirically for the co-polar signal variation after averaging 20–30 days of clear weather data, was of the form:

$$\text{Co-polar voltage } (V) = 3.25 + 0.17\left(\sin\frac{(t-9)\times 360}{24} + K\right)$$

where t = time of measurement in hours Universal Time (UT). K = a correction constant derived from the most recent clear sky data.

RESULTS OF THE TESTS

Individual Events
MODERATE RAIN. The variation of attenuation and cross-polar isolation during the passage of a typical weather frontal system over the Crawley Court site is shown in Fig. 4a (the large pulses occurring at two-and-a-half-hour intervals are calibration pulses and

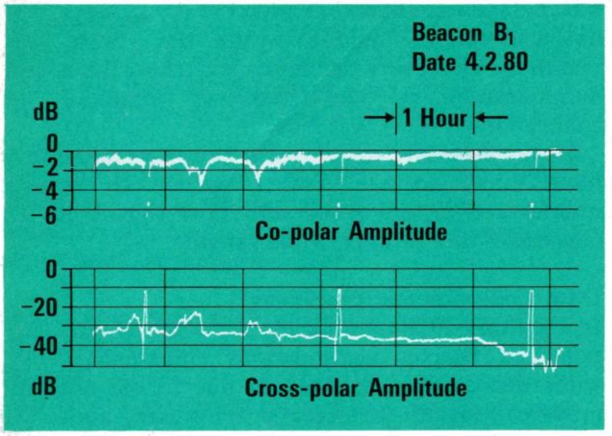


Fig. 4(a). Variations of attenuation and cross-polar isolation during rain showing good correlation (OTS Beacon B1 circular polarisation).

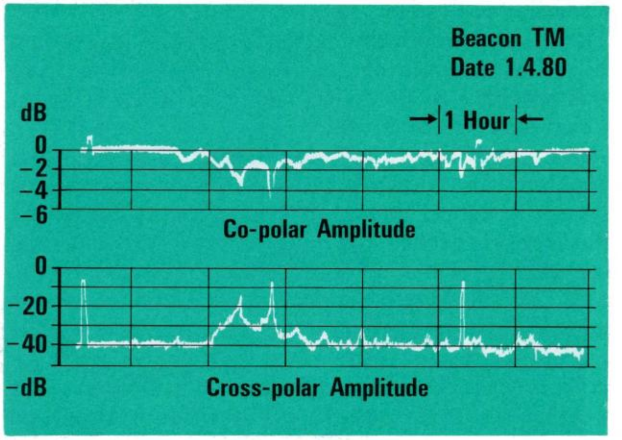


Fig. 4(c). Variations of attenuation and cross-polar isolation during rain, showing poor cross-polar isolation under conditions of moderate fading (OTS Beacon TM linear polarisation).

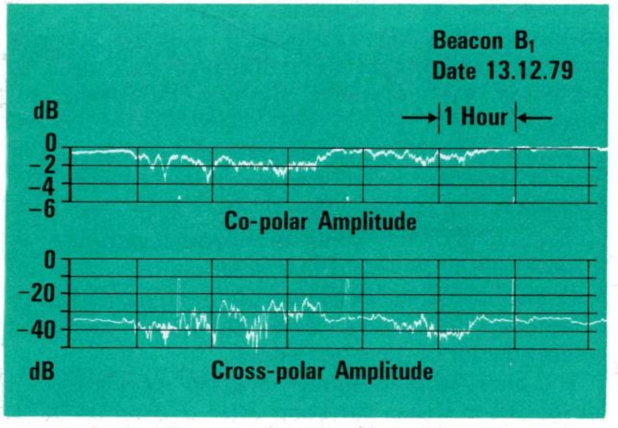


Fig. 4(b). Variations of attenuation and cross-polar isolation during rain showing poor correlation (OTS Beacon B1 circular polarisation).

should be ignored). In such conditions, peaks of attenuation rarely exceeded 2 dB and cross-polar isolation was rarely less than 20 dB. There is normally good correlation between attenuation and cross-polar isolation, as illustrated. Occasionally, however, correlation is poor, as shown in Fig. 4b. Conditions for rather more severe weather and for linearly polarised signals are shown in Fig. 4c.

SEVERE STORM. A severe storm occurred on 13th June 1979 accompanied by torrential rain. A plot of the received signal is shown in Fig. 5. The event is remarkable in that, for 20 minutes, the attenuation exceeded 7 dB. Such severe attenuation could result in the complete loss of a television picture from a domestic direct broadcast receiving installation.

SCINTILLATION. Scintillation (a fast variation) of the signal is a common phenomenon. Peak-to-peak variations are usually of the order of 1–2 dB (Fig. 6).

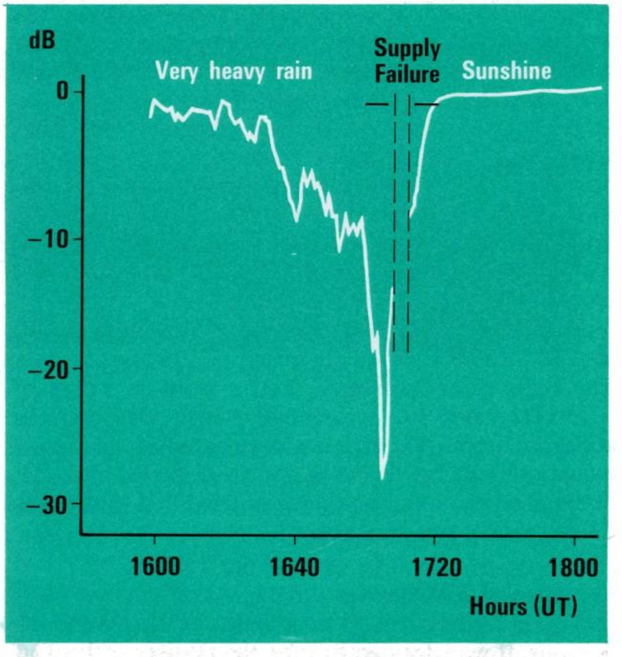


Fig. 5. Exceptional fade in severe storm (13th June 1979, OTS Beacon B1 circular polarisation).

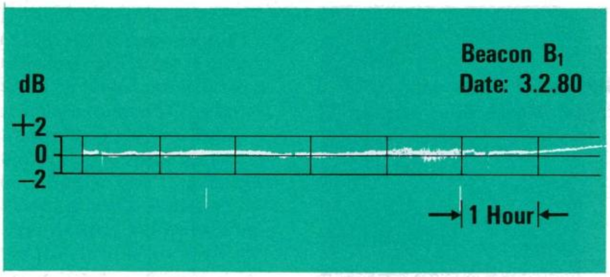


Fig. 6. Scintillation of the circularly polarised OTS Beacon B1.

SNOW. On several occasions accumulations of snow built up on the surface of the dish and subreflector. While the snow remained hard frozen, attenuation was found to be less than 3 dB. When the snow became wetted (or had begun to melt), very severe loss of signal occurred. In one case an attenuation of 30 dB was measured.

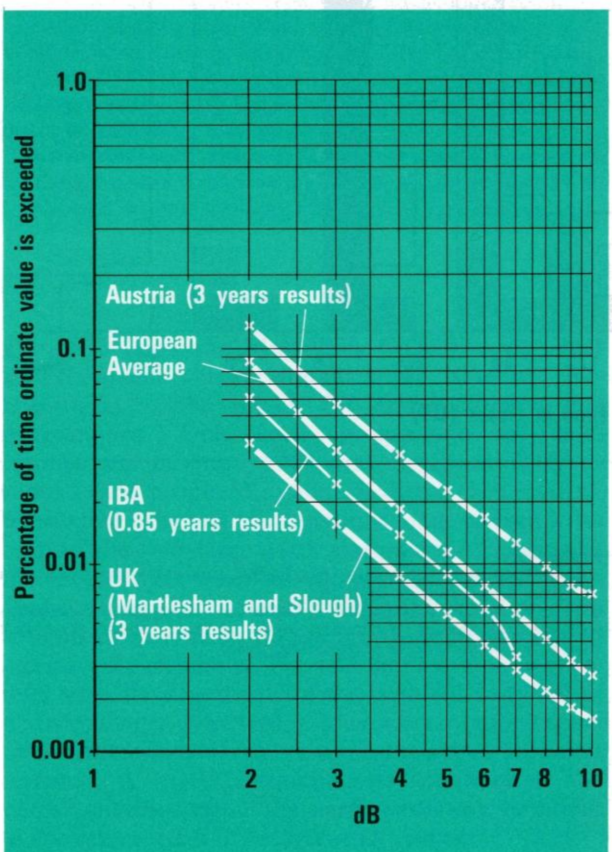


Fig. 7. Cumulative attenuation results.

Losses due to snow could contribute very significantly to outage times of domestic broadcast installations unless special design features are included in the aerial design to limit the accretion of snow on the reflector and the aerial feed. The snow events were regarded as untrue propagation phenomena because the loss was caused not by atmospheric conditions, but by deposits on the aerial.

Consequently, data obtained during such periods were excluded from the cumulative statistics.

Cumulative Statistics

The distribution of attenuation against time for prolonged periods is shown plotted in Fig. 7. This reveals that, for 0.06% of the time, attenuation was greater than 2.0 dB; and that, for 0.01% of the time (about 50 minutes per year), it exceeded 4.5 dB. These results are for linear polarisation and were obtained during 1980. For comparison purposes, cumulative results from other experiments via the OTS are also shown in Fig. 7.

Figure 8 shows the diurnal distribution of fades. For the deeper fades the incidence was found to be highest between 14.00 and 18.00 hours.

CONCLUSIONS

The OTS propagation results obtained at Crawley Court indicate that a propagation loss of 2 dB is exceeded for 0.06% of the time, corresponding to total time of seven hours within any calendar year.

For 0.006% of time, the propagation loss exceeded 6 dB, corresponding to total time of 32 minutes within one year.

Most fades which exceed 2 dB in amplitude occur in the afternoon or early evening hours, i.e. 12.00–21.00 hours UT.

Cross-polar isolation measurements have indicated that there is normally good correlation between the degradation of isolation and the level of co-polar loss, although, on one or two occasions, the level of cross-polar isolation fell with no corresponding fall in the co-polar signal level. The level of isolation has also fallen without a corresponding fall in the level of the co-polar signal. The level of isolation can fall to less than 20 dB during major events; but, usually, the level of co-polar signal level then also decreases by more than 5 to 6 dB. Hence, if a Band VI television signal were being received, it would be at or below threshold. Therefore, in general, a low level of cross-polar isolation would not significantly reduce the total amount of time that a service is available.

Future satellites which carry propagation beacons

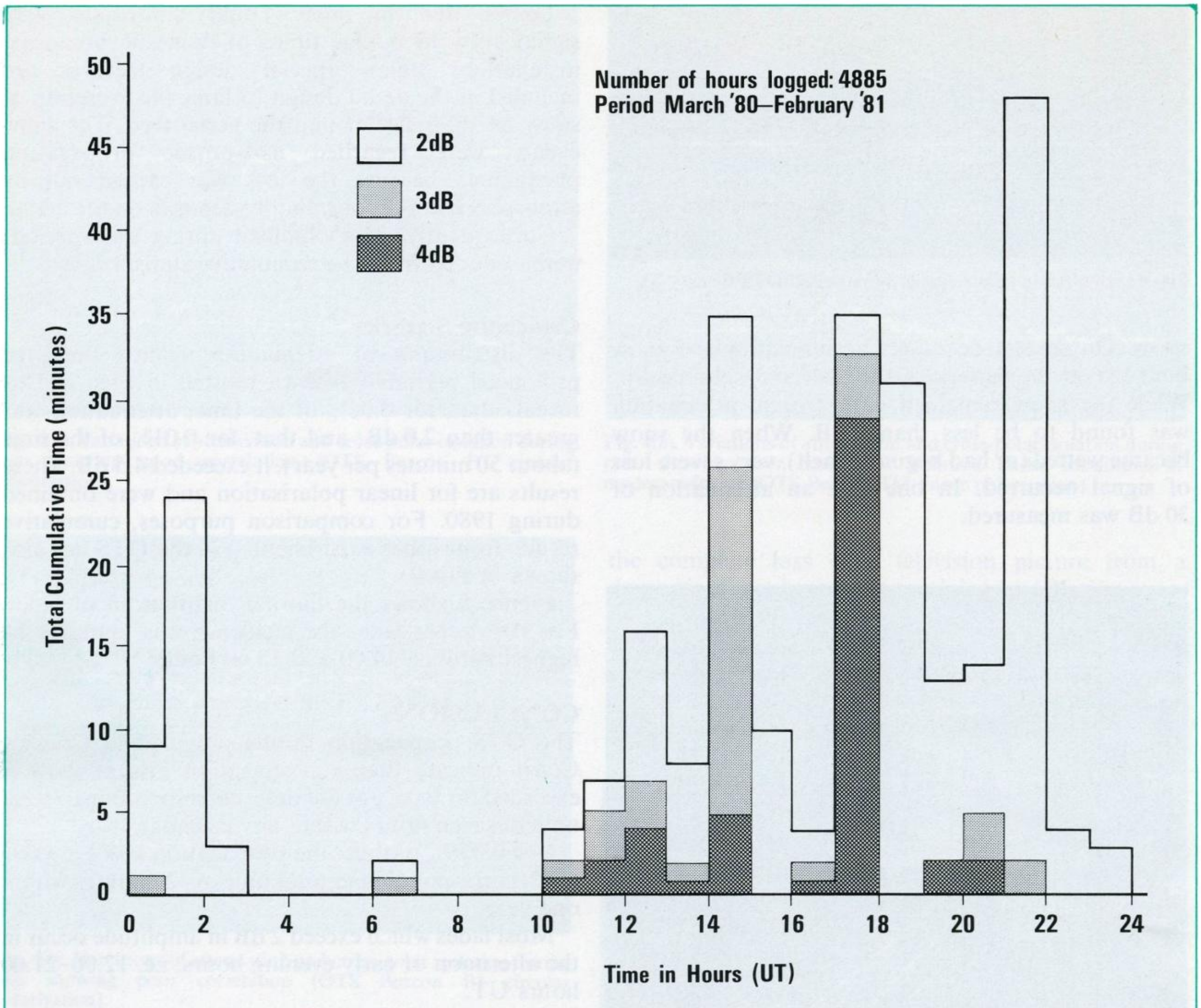


Fig. 8. Diurnal distribution of fading.

should, preferably, employ high stability systems. These can enable much simplification in earth station receiver design, and render much easier the analysis of results.

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2. P. A. Watson, N. J. McEwan & F. Dintleman, 'Propagation Experiments with the OTS Satellite: Preliminary report on results suitable for system design'. *Report for Interim Eutelsat* (Dec. 1980).

DAVID GRIFFITHS
C.Eng., MIEE started his broadcasting career in 1966 when he joined the BBC as a graduate trainee at Daventry transmitting station. Subsequently, he spent periods in both Studio and Transmitter Planning and Installation Departments, before joining the IBA in 1975 to work on the continuing expansion of the IBA's television and radio networks.
He has been involved in the IBA's television experiments with the European Test Satellite OTS since its launch in 1978 and has been a member of the EBU Specialist Group R3-OTS. He is now a Principal Engineer in the Network and Service Planning Department.

Analogue Television Tests with OTS

by D. C. Griffiths

Synopsis
In May 1978, the first European experimental telecommunications satellite OTS was launched successfully. The OTS satellite uses the 11 and 14 GHz frequency bands. The satellite down-link at 11 GHz is close to the 11.7 to 12.5 GHz band planned for satellite broadcasting, making it particularly suitable for experiments related to direct broadcasting satellites.

A programme of direct broadcasting tests, co-ordinated by the European Broadcasting Union began in June 1979. It involved up-link stations in the UK, France, Germany and Italy, and many small receiving terminals throughout Europe. The IBA took part in these tests using its 3-metre diameter receiving terminal located at Crawley Court, Winchester.

This chapter briefly describes the main objectives of the tests, the transmissions made and some of the results obtained. These results confirm the practicality of introducing national television satellite broadcast services for European countries based on the plan adopted at the 1977 World Administrative Conference.

Since its launch in May 1978, OTS, Europe's first experimental telecommunications satellite, has been used as the vehicle for many different test programmes. One such programme of tests commenced in June 1979 and deployed OTS to simulate the proposed system of direct broadcasting by satellite. The test transmissions made in turn from each of the four large earth stations participating in the OTS project were co-ordinated by the European Broadcasting Union (EBU). Reception took place in a number of countries throughout Europe using small receive-only terminals. The IBA participated in these tests with its 3-metre diameter terminal installed at Crawley Court, Winchester. This chapter reports some of the measurements made using the IBA's receiving terminal. A more comprehensive summary of the results obtained by all the participants can be found in the relevant EBU Technical Document[1].

Television tests have also been carried out amongst large earth stations to verify the point-to-point transmission performance for the EBU's 'Eurovision' network. The results of these tests have been reported elsewhere[2].

The Experiment

In Region 1, direct broadcasting by satellite in the band 11.7–12.5 GHz has been planned to provide a total of forty channels, each of 27 MHz bandwidth[3]. The quality of reception of such a television service is determined by several factors, including the power flux density from the satellite and the modulation system used. The continuity of reception will depend upon the margins available which give the viewer protection against changes in propagation conditions and interference from adjacent satellites.

Frequency modulation was assumed in the planning although other modulation schemes are permitted provided that they cause no greater interchannel interference than the reference frequency modulation systems. The broadcast satellite system

will operate with relatively small margins above the FM noise threshold; it was therefore highly desirable that practical measurements be carried out with an in-orbit satellite to confirm the service planning. OTS provided a unique opportunity for broadcasters in Europe to check not only propagation factors in this part of the frequency spectrum, but also the picture and sound transmission performance.

The Satellite

OTS is a geostationary satellite containing pairs of transponders with bandwidths of 5, 40 and 120 MHz. Transmission to and from the satellite uses the 14 and 11 GHz frequency bands with frequency reuse by polarisation discrimination. The direct broadcasting tests have been carried out using the two 120 MHz-wide satellite channels. These channels, designated 4 and $\bar{4}$, operate on a common frequency with linear polarisation separated orthogonally. These channels are chosen because they operate into a 'Spotbeam' antenna on the satellite providing the highest available effective isotropic radiated power (e.i.r.p.) of +47 dBW. This provides a power flux density on the ground of about -115 dBW/m^2 at beam centre. All the small terminals taking part in the experiment were located within the 4 dB contour of the 'Spotbeam' antenna as shown in Fig. 1. This power flux density can be compared with the minimum power flux density of -103 dBW/m^2 specified as the limit of the service area in the 1977 WARC broadcast satellite plan. The down-link frequency band used with OTS makes it particularly suitable for these experiments since it is directly below the 11.7–12.5 GHz broadcasting band. This relationship is shown in Fig. 2.

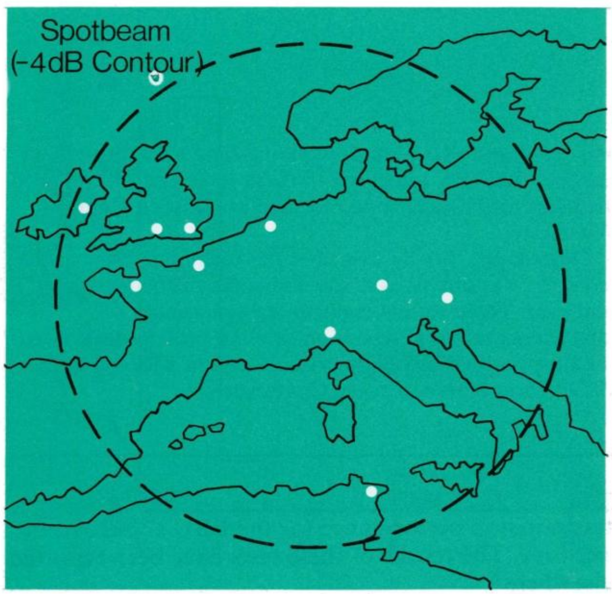


Fig. 1. Approximate coverage of the 'Spotbeam' (-4 dB contour) and locations of the receiving terminals.

The Receiving Terminal

The satellite broadcasting plan assumes that the receiver will have a minimum figure of merit (G/T) of 6 dB/K. To simulate the same carrier-to-noise conditions as would be experienced with the direct broadcast satellite when receiving from the OTS 'Spotbeam' the receiver G/T must be increased to compensate for the lower satellite e.i.r.p. A G/T of approximately 22 dB/K is required to achieve the same conditions at the -4 dB contour of the OTS beam. This can be achieved with an aerial of 3 metres in diameter and a receiver noise temperature of not more than 450 K.

Aerials larger than 3 metres in diameter require

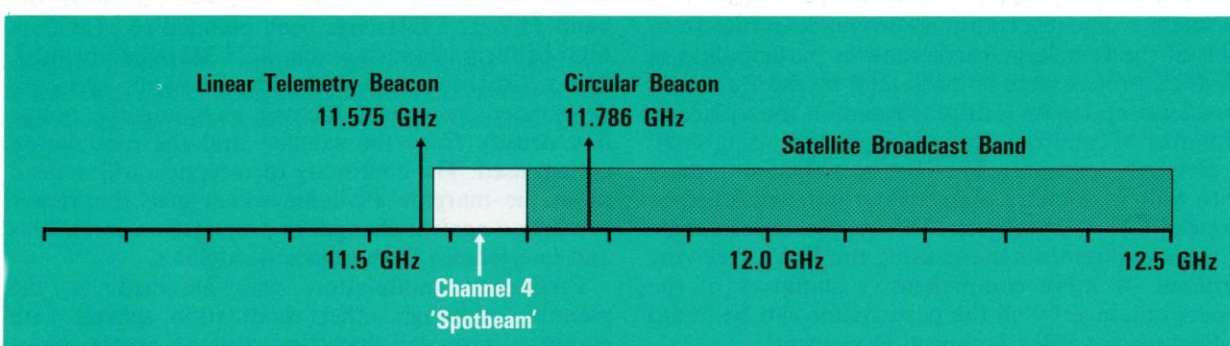


Fig. 2. The frequencies of the OTS beacons and of the spotbeam channel shown adjacent to the planned frequency band for direct broadcast satellites.

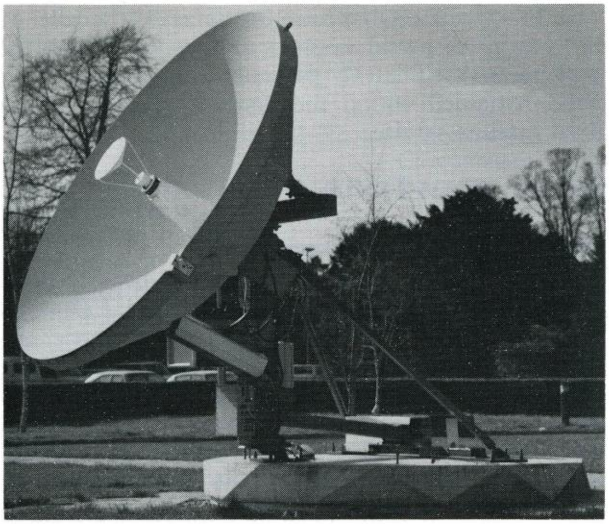


Fig. 3. The 3-metre diameter receiving aerial at Crawley Court.

tracking to retain correct pointing. To achieve a noise temperature of 450 K or below some form of low-noise amplifier will be required in front of the first mixer.

The 3-metre aerial at Crawley Court is shown in Fig. 3. The location of the aerial is 51.12°N, 1.39°W. The characteristics and performance of the IBA aerial and receiver at Crawley Court are summarised in Table 1.

The receiver is in two parts. The low-noise parametric amplifier is mounted near the aerial feed, where the first down-conversion to an intermediate frequency of 750 MHz takes place. A low-loss cable 100 metres long feeds the signals into the laboratory where they are converted to the second intermediate frequency of 70 MHz. Filtering and IF amplification is followed by the discriminator, after which the video signal and sound sub-carrier(s) are separated. A simplified block diagram is shown in Fig. 4.

TABLE 1—CHARACTERISTICS OF THE RECEIVING TERMINAL

AERIAL	
Diameter:	3 metres
Maximum gain on axis:	49 dB
Polarisation:	Linear or Circular
Polarisation discrimination on axis:	> 35 dB
Incremental pointing accuracy:	±0.02°
RECEIVER	
Dual frequency conversion:	
First IF:	750 MHz
Second IF:	70 MHz
Tuning Range:	11.45 – 11.8 GHz
Noise temperature (clear weather):	250 K
Equivalent noise bandwidth:	25.2 MHz
G/T nominal (clear weather):	25 dB/K
Pre-detection carrier-to-noise ratio:	18.5 dB

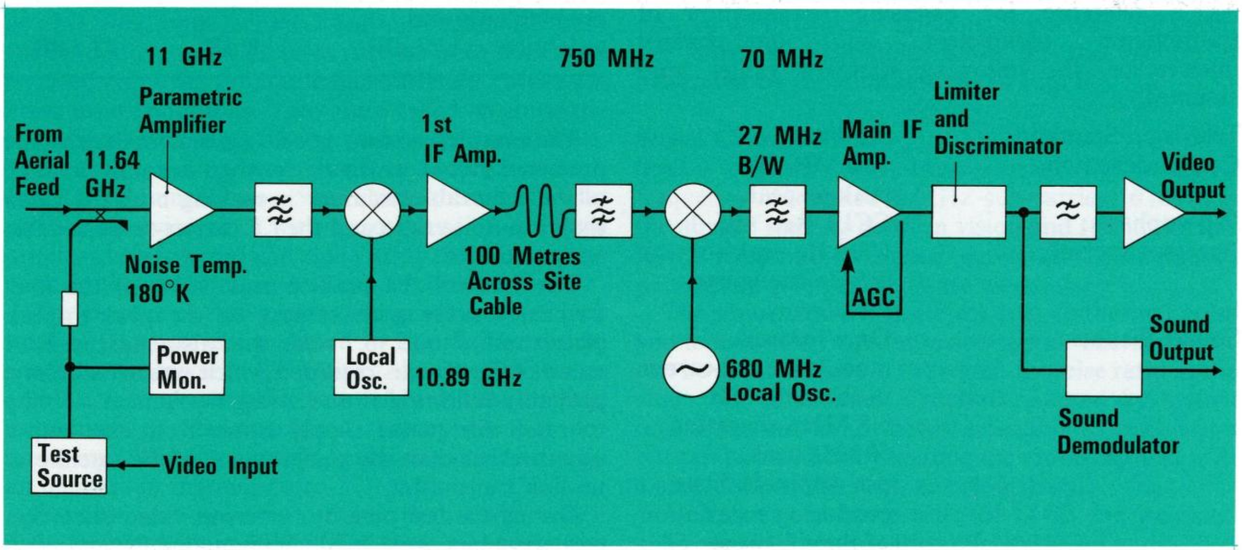


Fig. 4. A simplified block diagram of the television receiver.

Test Transmissions

The main objectives of the tests were:

(*a*) To determine, by objective measurements and subjective assessments, the picture and sound quality achievable when using the reference parameters adopted by the 1977 World Administrative Radio Conference (WARC '77).

(*b*) To determine whrether or not the reference parameters are optimum for a channel bandwidth of 27 MHz.

(*c*) To establish the extent of correlation, if any, between the propagation effects of attenuation and deplorisation and the resulting degradation of the television signal.

The test transmissions required fall naturally into two categories:

Short-term tests in which specific measurements are made to evaluate a particular parameter, e.g. sound channel measurements, subjective picture grading, etc.

Long-term tests which are aimed at finding correlation between the propagation factors and subjective picture quality. In order to have results over a range of different propagation conditions it was necessary to monitor and record video parameters over a long period of time. Use was made of nights and weekends when the satellite was not required for other tests. Automatic monitoring and recording equipments were used.

Reference Parameters

As a reference for assessing optimisation of transmission parameters, and inter-channel interference, the following standard values were assumed:

Television Standard:	625-lines
Carrier deviation:	13.5 MHz/V peak-to-peak
Pre-emphasis:	CCIR Rec. 405–1
Energy dispersal:	600 kHz peak-to-peak (25 Hz triangular waveform)
Sound channel:	On a frequency modulated sub-carrier in the range 5.5–6.5 MHz, deviation 50 kHz peak, pre-emphasis 50 μs producing a deviation of the r.f. carrier of 2.8 MHz peak.

In practice it was necessary to increase the level of the energy dispersal applied to a value of 2 MHz peak-to-peak, so that the power flux density per 4 kHz band remained within the limits applicable to the fixed satellite service.

SHORT-TERM TESTS

Objective Picture Measurements

The ratio of the r.m.s. noise to the peak-to-peak picture amplitude of 0.7 volt was measured. From this result the value corresponding to a received carrier-to-noise ratio of 14 dB was calculated assuming a linear relationship above the FM threshold. Measurements were made, both flat and weighted using a unified weighting network conforming to CCIR Recommendation 567 (Report 486–1). The predicted and measured values are shown in Table 2.

TABLE 2—PREDICTED AND MEASURED S/N RATIOS

	PREDICTED S/N AT 14 dB C/N	MEASURED VALUE
FLAT (includes effect of pre-emphasis = 2.0 dB)	33.6 dB	33.0 dB
WEIGHTED (includes effect of pre-emphasis and weighting = 13.2 dB)	44.8 dB	43.5 dB

The results show good agreement with the predicted values, particularly when account is taken of the achievable accuracy in making both the video signal-to-noise ratio and the r.f. carrier-to-noise ratio measurements.

The ratio of the peak-to-peak value of the low-frequency noise with respect to the peak-to-peak picture amplitude (0.7 volt) was also measured. A value of 35 dB was recorded which was satisfactory, probably reflecting the receiving equipment's ability to reject the mains supply ripple from the output signal rather than the performance of the satellite or up-link transmitter.

During the test period, numerous video distortion measurements were made both manually and with automatic measuring equipment using the field-

TABLE 3: DISTORTIONS—TYPICAL VALUES

NON-LINEAR DISTORTIONS		LINEAR DISTORTIONS	
Luminance non-linearity	2–3%	Luminance-Chrominance inequality	
Differential Gain	1–2%	(i) Gain	1–1.5 dB
Differential Phase	1–2°	(ii) Delay	20 ns
Synchronising Pulse distortion	0%	K Ratings	
Chrominance-Luminance intermodulation	0%	(i) Pulse-to-Bar Ratio	1.5%
		(ii) Pulse	2%
		(iii) Bar	2%
		(iv) 50 Hz	0%

blanking test lines which were always present. Typical measured results are given in Table 3.

It should be noted that these results include the impairments from the complete satellite broadcasting system, including the up-link transmitter, satellite repeater and down-link receiver but excluding the studio and studio to earth-station link.

In order to remove the sub-carrier used for the accompanying sound signal, a low-pass filter was fitted to the video output of the receiver. Sub-carrier frequencies as low as 5.5 MHz were used in these tests necessitating the use of a filter with a sharp cut-off. This filter accounted for most of the linear distortion present.

Subjective picture quality assessments were carried out for the reference transmission parameters. Panels of observers, both technical and non-technical, were shown a sequence of pictures derived from slides and received from the satellite under different carrier-to-noise ratio conditions. They were asked to grade the resulting picture using the five point impairment scale. The viewing arrangements were in accordance with CCIR Recommendation 500. The sequence of slides was shown twice, once with the carrier-to-noise ratio progressively lowered and again using the same values of carrier-to-noise ratio, but in a random order.

The average picture impairment grade assessed by a total of 23 observers is shown in Fig. 5. The results confirm that towards the limit of the satellite service area, i.e. a carrier-to-noise ratio of 14 dB, the average impairment is about grade 4 (perceptible but not annoying). The impairment is almost entirely due to an increase in thermal noise.

For carrier-to-noise ratios lower than 12 dB, which is the point where impulsive FM threshold noise first appears, the subjective picture impairment ratio deteriorates rapidly. With a carrier-to-noise ratio of 10.5 dB, the average picture impairment was grade 2 (annoying). These results were obtained using conventional demodulators. Special threshold extension demodulators can provide pictures substantially free from threshold noise several dB's below these carrier-to-noise ratios. These designs are not expected to be used by individual viewers but may find an application in communal systems. However, the effect of threshold noise on the picture is illustrated by the photographs in Fig. 6.

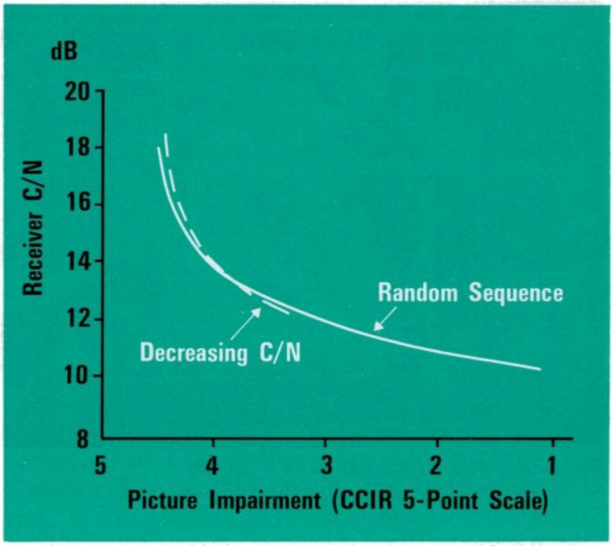


Fig. 5. The variation of picture impairment as a function of carrier-to-noise ratio.

— slides shown in random order.
– – slides shown in order of decreasing C/N.

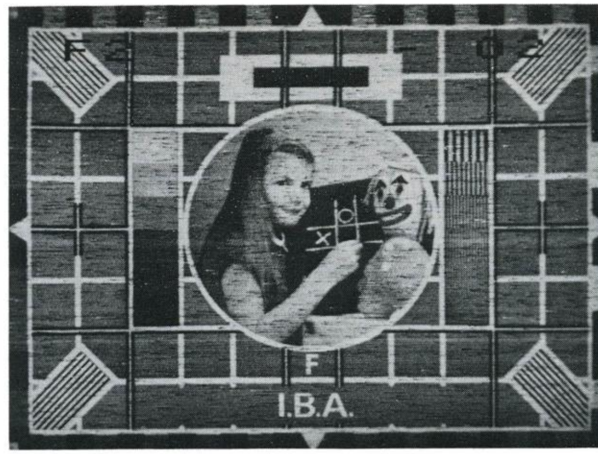
Sound Channel Tests

Sound channel tests were carried out using a frequency modulated 6 MHz sub-carrier; 6 MHz is the normal spacing between vision and sound carriers in the terrestrial broadcast networks. The reference parameters given earlier were used.

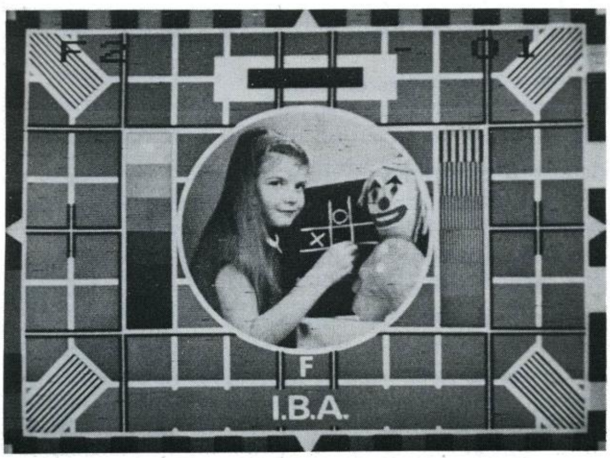
The sound channel is subject both to thermal noise and to crosstalk from the vision signal. Thermal noise can be calculated from the signal-to-noise ratio in the video bearer channel. Crosstalk, caused by system non-linearities, is not easily amenable to calculation but can be assessed by loading the vision channel with a severe waveform such as colour bars.

At a carrier-to-noise ratio of 14 dB the weighted audio signal-to-noise ratio (referred to an audio level corresponding to the peak deviation of the sub-

Reception within service area (C/N > 14 dB)



Reception below FM threshold (C/N < 10 dB)



Reception at FM threshold (C/N = 10–12 dB)

Further reduction of C/N causes picture to degrade rapidly (external syncs were required to lock this picture)

Fig. 6. Off-screen photographs illustrating the effects of FM threshold noise.

carrier) is approximately 46 dB. This assumes a quasi-peak measuring instrument and a noise weighting network in accordance with CCIR Recommendation 468–2. Noise measurement referred to 0 dBm, or Level 4 on a peak programme meter, will be 8 dB lower. The measured values at other carrier-to-noise ratios are shown in Table 4.

It was also noted that without the video colour bar signal present the sound channel signal-to-noise ratio was approximately 1 dB greater. The measured values for thermal noise, excluding crosstalk, were therefore found to be close to those predicted.

Effect of Sound Sub-carriers on the Pictures

The presence of a sound sub-carrier above the video has an effect on the received picture quality because:

(i) A slight reduction occurs in the picture signal-to-noise ratio due to the deviation of the main carrier by the sound sub-carrier.

(ii) Intermodulation between the picture components and the sound sub-carrier causes products which fall in the video band.

Measurements confirm that the effect of (i) is to reduce the available video signal-to-noise ratio by

TABLE 4: SOUND CHANNEL PERFORMANCE

CARRIER-TO-NOISE RATIO (dB)	AUDIO SIGNAL-TO-NOISE WEIGHTED	PICTURE QUALITY (COLOUR BAR MODULATION)
18.4	49.5	Free from threshold noise
16.4	47.0	Free from threshold noise
14.9	45.5	Free from threshold noise
13.1	43.0	Occasional noise spikes
11.4	41.0	10–20 noise spikes
10.0	38.5	100–200 noise spikes

about 0.2 dB. Intermodulation can cause further degradation but the total loss of video signal-to-noise is generally less than 0.5 dB with a single sub-carrier.

The IBA also took part in tests using two sub-carriers above the video to carry two discrete sound channels. In this case the reduction in weighted video signal-to-noise can be as high as 1.5 dB. Intermodulation between the sub-carriers was sufficient under certain conditions to produce patterning in horizontal bands across the picture. This effect was not observed at all terminals taking part in the experiment. Inadequate filtering of the sub-carrier(s) from the video signal caused undesirable effects on some monitors. With adequate filtering, there was little subjective effect on the picture for single sub-carrier systems provided the sub-carrier deviation was limited to 2.8 MHz peak. Using a single sound sub-carrier and a domestic television receiver the sound quality was good. However, when audio signals were reproduced by a hi-fi system at a reasonable listening volume, thermal noise was quite apparent during periods of low programme modulation.

LONG-TERM TESTS

For the long-term tests, a signal was transmitted consisting of EBU colour bars with Insertion Test Signals (ITS) inserted on the international lines 17 and 18, 330 and 331 in the field-blanking period.

The quality of the received signal was monitored continuously by an automatic analyser operating on the ITS waveforms. During periods of normal or undisturbed propagation the measured ITS parameters were recorded onto paper tape at intervals of five minutes. Thus during a day of clear weather some 288 samples each of thirteen parameters of the ITS were recorded. As part of the IBA's propagation experiment the circularly polarised B beacon was also

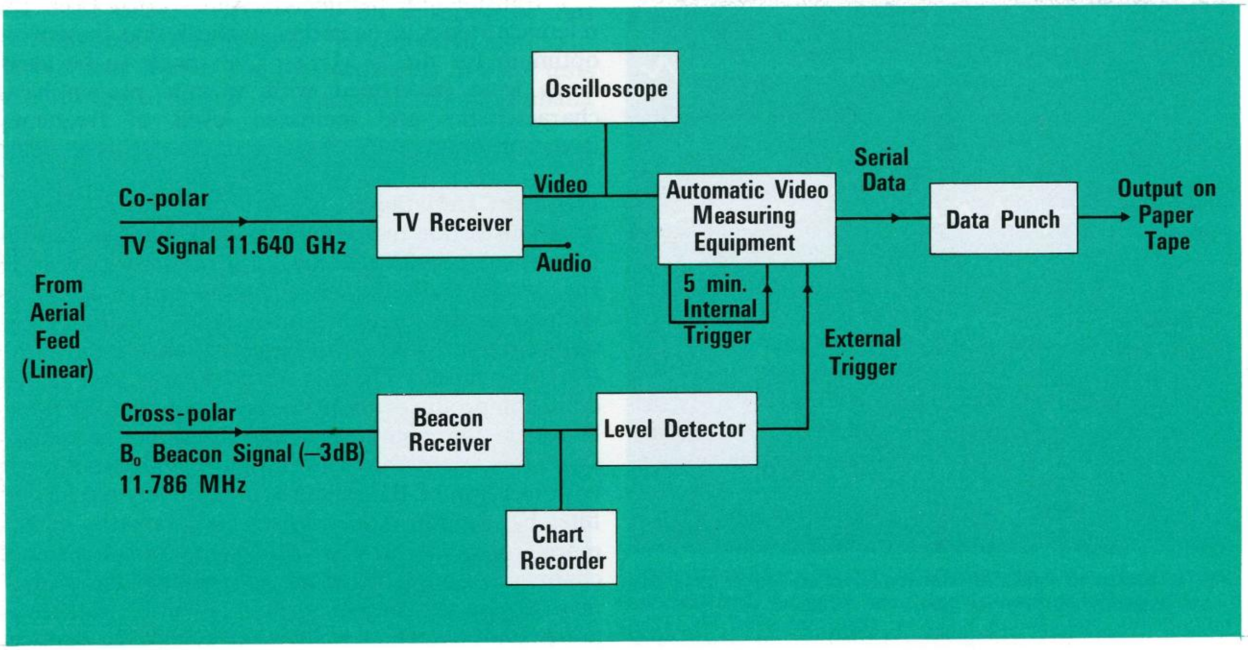


Fig. 7. Block diagram of long-term recording equipment.

being received from the satellite. Use was made of the beacon signal level to indicate a change in propagation conditions.

A fall in beacon signal level greater than 2 dB resulted in ITS parameters being recorded continuously. In practice the maximum sampling rate was limited to about four per minute because of the time taken to output each set of samples onto paper tape. A block diagram of this arrangement is shown in Fig. 7.

Recordings were made for over 1,000 hours. During this time, several signal fades occurred due to rainfall on the down path. During one such event which occurred due to heavy rainfall on 30th July 1979, the signal was attenuated below the FM threshold of the receiver. No events were observed due to fading on the up-path. Signal fading on the up-path would in any case be masked by the non-linear characteristic of the satellite output travelling wave tube amplifier operating at saturation and the rapid sampling system triggered by the down-path beacon would be inoperative.

The video (ITS) parameters measured during faded conditions have been compared with those obtained on a clear day. With a constant video signal-to-noise ratio at the input to the measuring equipment there is an inherent spread on the measured value. This spread increases as the video signal-to-noise ratio is reduced. Figure 8 shows the measured values of differential phase on 23rd June, when the signal-to-noise ratio fell from 47 dB to signal drop-out. It should be noted that in this case the horizontal scale is non-linear due to the increased sampling rate below 2 dB of fade. The only effect on the differential phase is an increased measurement spread, which is due to the measuring equipment's reduced accuracy at low signal-to-noise ratios. Similar behaviour is experienced on all the video parameters recorded, which were:

Bar amplitude
Sync amplitude
2T pulse-to-bar ratio
Chrominance-luminance gain and delay inequalities
Luminance non-linearity
Chrominance-luminance crosstalk
Low frequency error
Bar tilt
2T 'K' rating
Differential phase
Differential gain

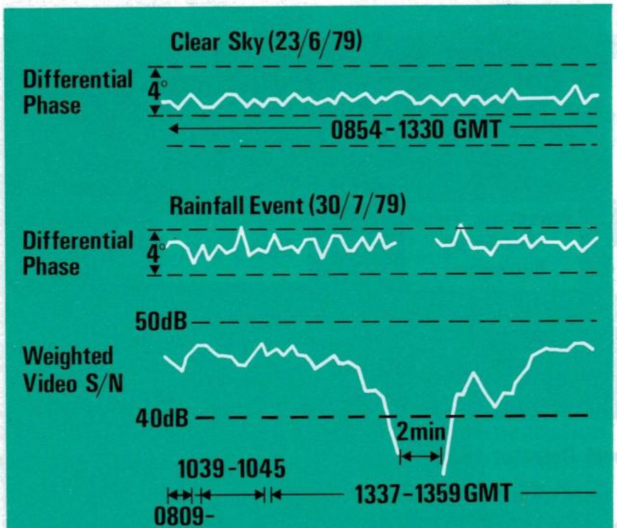


Fig. 8. Measured values of differential phase on a clear day (23.6.79) and of differential phase and weighted signal-to-noise ratio before and during a heavy rainstorm (30.7.79). (The horizontal time-scale changes when the signal-to-noise ratio falls 2 dB below the nominal value of 47 dB.)

RESULTS OF OTHER TESTS

Optimisation of Transmission Characteristics

The transmission parameters were varied from the reference values given earlier to check that these were optimum for the 27 MHz r.f. channels to be used. Tests were performed with various pre-emphasis characteristics and increased levels of frequency deviation.

Frequency Deviation

Video distortion measurements were made at various frequency deviations. Some of the results are shown in Fig. 9. Generally, higher deviation brings about an increase in the levels of non-linear distortion. There was also some loss of chrominance as the deviation level was raised. There is an advantage that higher deviation produces an increased signal-to-noise ratio; however, the point at which threshold noise first appears is raised above the normal FM threshold, due to truncation of the signal by a relatively narrow IF filter bandwidth. Added system non-linearity causes more crosstalk from the vision signal into the sound channel, although this disadvantage is offset for small increases in deviation by a small reduction in thermal noise. On balance, it is felt that 13.5 MHz peak-to-peak deviation is about optimum in this application.

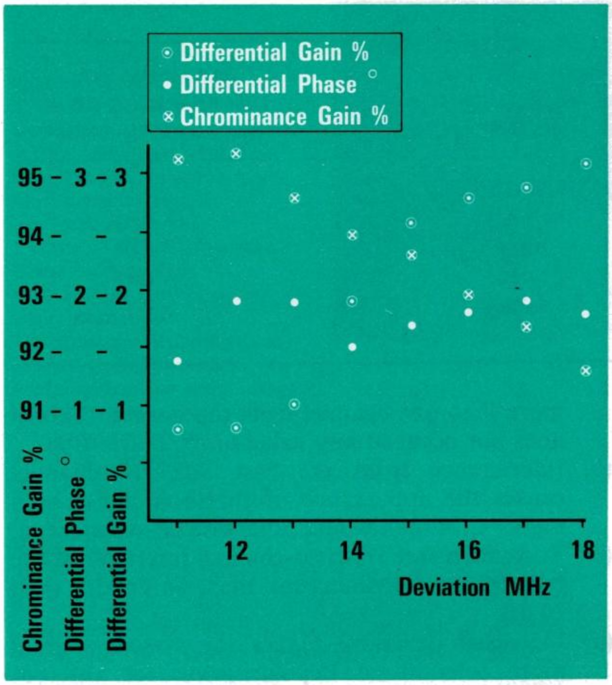


Fig. 9. Measurements of video distortion as a function of FM deviation.

Pre-emphasis

Three types of network put forward by D'Amato and Stroppiana[4] were tried in a series of test transmissions made from the Italian earth station at Fucino near Rome. The IBA took part in these tests which were arranged by Radiotelevisione Italiana (RAI) who also supplied matching de-emphasis networks for the receiver. As can be seen from Fig. 10, compared to the standard CCIR network, these networks give a greater reduction in the lower frequency deviation, and so could improve the overall linearity. As previously noted, there was no obvious improvement using these networks because linear distortions are already low. Subjectively, the networks produced slightly degraded pictures when threshold noise was present. This was caused by horizontal extension of the threshold spots which was most noticeable where τ (the network pole time constant) was greatest. All things considered, there was no reason found to change from the existing CCIR network (Recommendation 405–1) originally agreed for monochrome television links using frequency modulation.

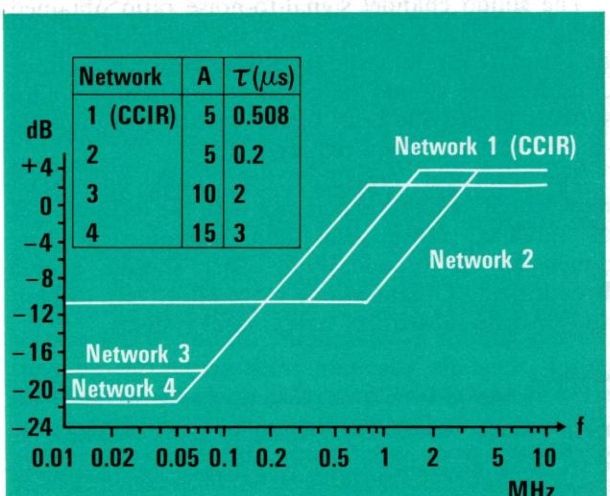


Fig. 10. The characteristics of the pre-emphasis networks used.

Teletext

Many test transmissions included teletext signals. Transmissions from the IBA included the 'ORACLE' test page. Performance was monitored by recording the decoding margin at regular intervals during the transmissions and observing the test page. The following were noted:

(i) The decoding margin varied between 56% and 83%. This variation is thought to have been caused by an intermittent connection in the experimental transmit or receive equipment.

(ii) Teletext performance was consistently good while the picture remained free from threshold noise. It was unaffected by the changes in the decoding margin noted above.

(iii) As the signal level was reduced the teletext signal was first affected by errors at a carrier-to-noise ratio of 11 dB, i.e. 1 dB below the first signs of threshold noise on the picture. About four text errors were observed over a ten-minute period.

(iv) For lower values of carrier-to-noise ratio the errors increase. At a point where the picture was unviewable, the page of text was still reproduced 90% correct.

The conclusion of the IBA is that the transmission of UK Teletext over a direct broadcasting satellite would be satisfactory.

Energy Dispersal

The satellite broadcast plan required that 600 kHz peak-to-peak of energy dispersal be used. Tests were carried out to find the effect of energy dispersal on typical UHF domestic television receivers. Three domestic receivers were fed via a UHF amplitude

TABLE 5: RESULTS FROM INTERFERENCE TESTS

DEVIATION (MHZ)	SPACING BETWEEN CARRIER FREQUENCIES	POLARISATION DISCRIMINATION FOR PERCEPTIBLE INTERFERENCE	POLARISATION DISCRIMINATION FOR INCREASE IN NOISE
13.5	Co-channel	20 dB	—
18.5	Co-channel	16 dB	(18 dB)
13.5	Adjacent-channel	none	(7 dB)
18.5	Adjacent-channel	none	(34 dB)
13.5/18.5	More than one channel away	none	—

modulator. As a reference, a professional quality monitor was fed direct with video (including energy dispersal). At energy dispersal levels up to 600 kHz there was no picture impairment. At 900 kHz there was line tearing on all three domestic receivers. However, this could be removed by reducing the UHF modulator input level by 2 dB, thus preventing over-modulation. At 1,200 kHz and above, line tearing on the domestic sets became progressively worse. Clearly, care must be taken to prevent over modulation of the UHF modulator, where remodulation is used. Over modulation can be caused by the increased excursion of the signal with energy dispersal present. Line-clamping within the domestic set appeared to cope with levels up to 600 kHz. The tests were not exhaustive and need to be repeated with a wider range of domestic receivers and other UHF modulators.

Interference Tests

Tests were carried out using both orthogonal channels on OTS to evaluate the effect of adjacent and co-channel interference. For these tests the level of polarisation discrimination was reduced by rotating the antenna feed of the receiving terminal until interference was 'just perceptible'. The level of depolarisation was then recorded using the co-polar and cross-polar levels of the TM beacon. This test was repeated with the deviation increased from the reference system value to 18.5 MHz. The results of these tests are shown in Table 5.

The value of polarisation discrimination shown in parenthesis is the point at which FM threshold noise appeared on the picture without moiré-type interference patterns.

From these limited tests, the results being recorded by only one station, it can be seen that:

(*a*) Interference from adjacent channels separated by more than one channel from the wanted channel does not occur at any value of depolarisation.

(*b*) Interference from the first adjacent channel causes the appearance of threshold noise at a higher C/N than would otherwise be experienced.

(*c*) To remain free from co-channel interference the polarisaton discrimination must be greater than 20 dB.

(*d*) Increased deviation makes the system slightly more tolerant of depolarisation for the co-channel case but less tolerant in the case of interference from an adjacent channel as one might expect from the increased spectrum spreading.

CONCLUSIONS

The tests described have confirmed the viability of satellite broadcasting using frequency modulation and 27 MHz-wide channels.

The sound channel signal-to-noise ratio obtained using a single sub-carrier above the vision signal may be adequate for domestic reception. However, serious consideration should be given to alternative sound systems to provide both better quality and multiple sound channels where required.

The practical measurements made with OTS represented valuable experience with the technologies of satellite transmission and reception, a new dimension in broadcasting. This should enable Broadcasting Organisations more effectively to plan and provide subsequent operational systems.

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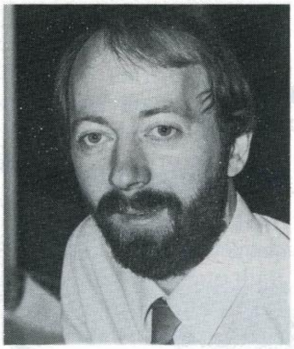
Since 1974, he has worked in the Independent Broadcasting Authority's Experimental and Development Department, on projects including SABRE (an adaptive receiving aerial array) and bit rate reduction methods for digital component television transmission.



A 60 Mbit/s Digital Video Codec

by E. J. Wilson

Synopsis
Techniques for the digital encoding of television signals have for many years been under study by the IBA. The special problems posed by the bit rate and error rate restrictions of a satellite transponder channel offered a challenge to the knowledge and experience previously gained. A video codec was therefore designed and developed specifically for satellite use to provide broadcast quality pictures even during conditions of fading. The resulting prototype was tested initially by simulating the characteristics of a satellite channel. Afterwards, in 1980 it was successfully proven in experimental transmission via OTS.

In April and July 1980 the Codec to be described was used successfully for the digital transmission of broadcast quality television pictures via the Orbital Test Satellite (OTS). These tests were consecutively the first in the UK to use a small (3 m) down-link dish aerial and the first to use both small up-link (2.5 m) and down-link (3 m) dish aerials for digital satellite television. The test results showed that digital coding of broadcast television signals is a particularly robust method for satellite transmission and is especially useful with small dish sizes where energy dispersal and low signal-to-noise ratios can render impracticable the conventional analogue (FM) methods.

The OTS includes analogue transponders with bandwidths of 40 MHz and 120 MHz. Digital signals, when used to suitably modulate an up-link carrier, may be carried by these analogue channels. Using Quarternary Phase-Shift Keying (QPSK) the 40 MHz transponder will accommodate 60 Mbit/s of data, and similarly the 120 MHz transponder up to 180 Mbit/s. It was envisaged in the original planning for OTS that test transmissions of digital burst mode telephony, the technique known as Time Division Multiple Access (TDMA), would be applied at various data rates through the satellite transponders. TDMA terminals and digital modulation equipments were to be developed for the purpose; indeed commercial QPSK modems at 60 Mbit/s and 120 Mbit/s are available in the UK.

Although optimised for burst-mode operation, these modems can be modified for continuous use and so can be used to transmit television signals, provided that the digital rate is 60 Mbit/s or 120 Mbit/s and that the interface levels are compatible. A consideration of the signal-to-noise ratio requirements for error-free television transmission using relatively small up-link and down-link dishes points to the use of the lower bit rate modems. Therefore, with that in mind, the IBA designed an equipment which would digitally sample a PAL System I video signal, and its associated audio component, and shoehorn the combination into 60 Mbit/s. This purpose-designed Codec was then built and used, with the close co-operation of British Telecom, for experimental broadcasts via OTS. These examined the potential benefits of digital transmission by satellite and proved

the various novel features of this particular Codec design.

THE DIGITAL VIDEO SIGNAL

During recent years much work has been reported on the digital coding of broadcast quality television signals. From a consideration of the Nyquist criterion, the lowest practical sampling frequency for a 5.5 MHz bandwidth signal is about 12 MHz, and each sample must be quantised to eight-bit accuracy, if no visible impairment is to be detectable. The minimum likely video data rate resulting is, therefore, about 96 Mbit/s. Impairments must occur if the digital signal is bit-rate reduced to below 60 Mbit/s; but, by suitable design, the subjective effect of the impairments can be minimised. The first technique employed is to sample the signal at an effective rate of twice the PAL sub-carrier frequency ($2\ f_{sc}$). With no further processing this would introduce unacceptable alias components caused by signal frequencies between 4.43 MHz and 5.5 MHz.

These beat effects can be avoided by pre-filtering the signal with a two-dimensional (spatial) filter, which removes signal frequencies likely to cause aliasing before the sampling process.

The signal frequencies attenuated by this filter are diagonal spatial frequencies and their loss causes only small impairment of pictures. In fact, some *improvement* in quality can result from the attenuation of those luminance diagonal frequencies which produce cross-colour effects.

A second stage of data rate reduction is also required, and many variations of the techniques of Differential Pulse Code Modulation (DPCM) could be used for this. A particularly good choice is Hybrid DPCM which has properties that can aid forward error correction and concealment of channel errors experienced during up-link or down-link fading.

THE DIGITAL AUDIO SIGNAL

As yet, no international standard for transmission of high quality digital audio has been agreed; it has to be taken into account that a satellite link may connect two continents, and several channels of sound may be required. A sensible option is, therefore, to provide a European standard 2,048 kbit/s digital transmission channel via the satellite, and to employ proprietary audio coding equipment, carrying six high quality audio signals in a multiplex of 2,048 kbit/s. It is likely that any future standard package of audio and data signals will be multiplexed to the same overall rate.

EXPERIMENTAL EQUIPMENT

The 60 Mbit/s Coder was designed to accept an analogue PAL System I video input and a European standard 2,048 kbit/s digital signal from commercial audio encoding equipment. As the block schematic diagram (Fig. 1) shows, the 60 Mbit/s Coder contains six major sub-systems. By comparison with the block schematic diagram shown in Fig. 2, it can be seen that there are similarly six sub-systems in the Decoder. The function of each Decoder sub-system is generally the exact inverse of one in the Coder, and so, only the Coder sub-systems are here described in detail. The

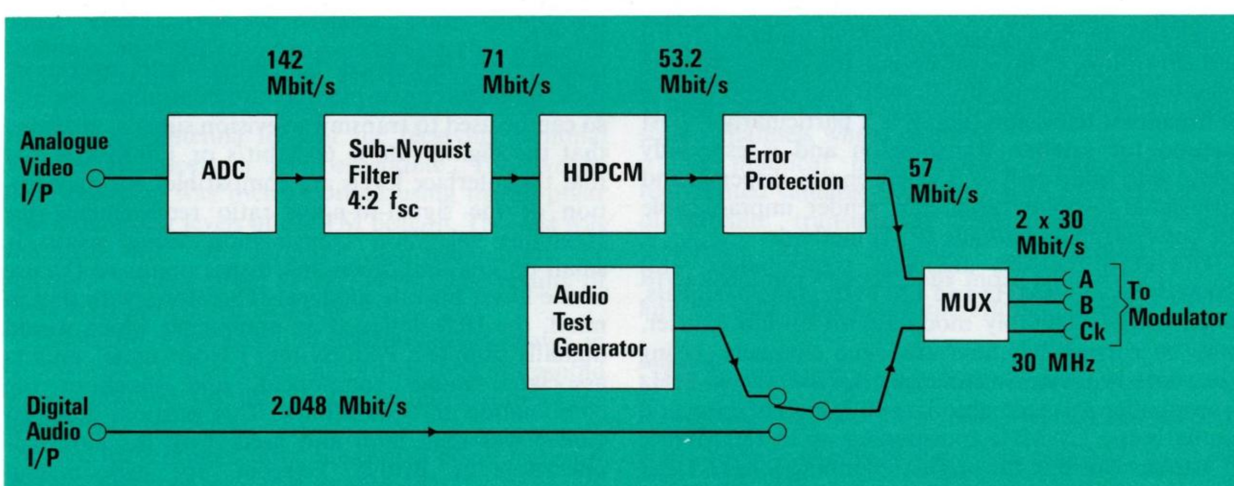


Fig. 1. Block diagram of the 60 Mbit/s coder.

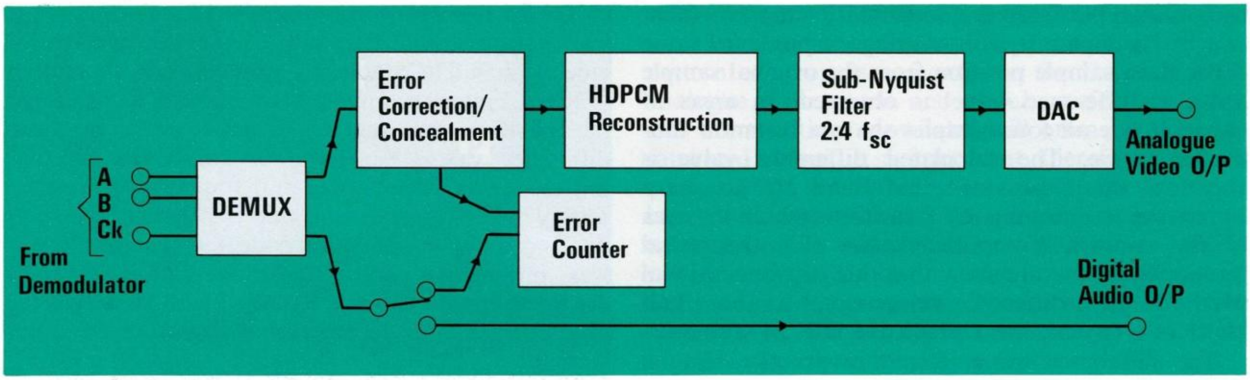


Fig. 2. Block diagram of the 60 Mbit/s decoder.

exceptions to this rule are the Audio Test Generator in the Coder and the Error Counter in the Decoder which together make possible accurate characterising of the satellite link error rate. For this purpose a test signal replaces the multiplexed audio signal. Other error counting provisions are therefore necessary when the link is operational and carrying audio signals.

Analogue-to-Digital Conversion

The PAL System I video signal is sampled at four times the PAL sub-carrier frequency (4 f_{sc}) using an eight-bit monolithic Analogue-to-Digital Converter (ADC). Ancillary functions such as synchronising pulse separation, analogue clamping and filtering, and phase-locked sampling clock generation require a total of four printed circuit boards in addition to that containing the ADC and drive circuitry. The digital signal resulting from this sampling has a rate equivalent to 142 Mbit/s.

Sub-Nyquist Filter

A two-dimensional digital filter (Taylor[1]) (a combination of horizontal low-pass and vertical comb filters) is used to attenuate diagonal spatial frequencies. Every alternate sample is then discarded, leaving a data stream sampled at 2 f_{sc}, so-called sub-Nyquist sampling[2] equivalent to 71 Mbit/s. The aliasing which occurs in the down-sampling process is in the same diagonal frequencies at which the spatial filter attenuated the original signal. The picture quality suffers only slight degradation by loss of diagonal resolution; but the vertical combing process seriously corrupts the ITS and Teletext lines in the field interval.

Hybrid Differential Pulse Code Modulation (HDPCM)

This sub-system reduces the bit-rate from 71 Mbit/s to 53.2 Mbit/s. Of each group of three eight-bit PCM samples in the input stream one remains unmodified and two are differentially encoded. The technique of combined PCM and DPCM is termed Hybrid-DPCM.

The differential encoding is two-dimensional, a typical five-line area of picture giving rise to PCM (P) and DPCM (D) samples in the pattern shown in Fig. 3. An interpolative predictor value is computed for

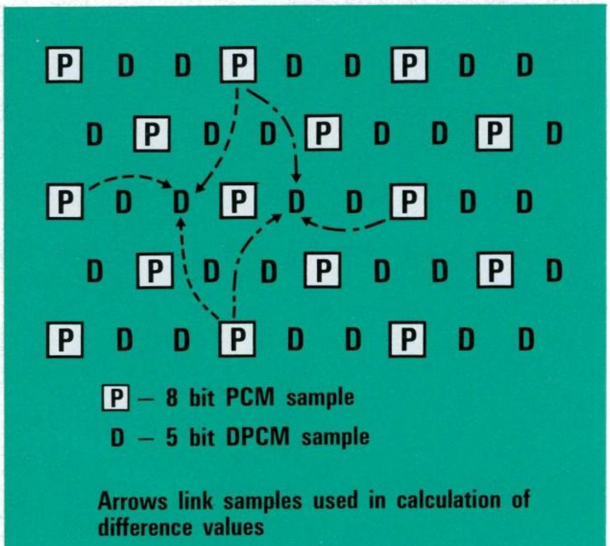


Fig. 3. The Hybrid-DPCM sampling pattern.

each D sample from the weighted average of three nearby P samples. By substracting the predicted value for a given sample position from the original sample value a 'difference value' is obtained. In areas of constant hue all four samples share a common sub-carrier phase. The calculated difference value is therefore small, provided that there are no sharp luminance or chrominance transitions within the area of the samples. Computer studies of a theoretical 'colour rings' picture show that this two-dimensional HDPCM gives difference values equal to about half those of a typical linear predictive DPCM scheme.

The difference values found in practice form a distribution symmetrical about zero, peaking at that value but extending in the extremes from −256 to +255.

In order to achieve the necessary saving in bit-rate, this range must be compressed for transmission into 31 'transmission codes'. The transmission code is a five-bit binary number, and, after compression, each original group of three eight-bit PCM samples is carried by a total of eighteen bits (8–5–5). The bit-rate reduced output is, therefore, 53.2 Mbit/s or 18/24 of the rate produced by the sub-Nyquist filter.

The compression law used for coding the difference values for transmission is optimised for the statistical distribution of difference values produced by a typical video signal. The practical non-linear law, illustrated in Fig. 4, is skew symmetrical about zero. Considering the positive quadrant, the three most common difference values 0, 1 and 2, are coded linearly. Difference values of three and four are represented jointly by the transmission code 3, difference values of five and six by transmission code 4, and so on. In this way, progressively more and more difference values are represented by each transmission code, so that the final positive code 15 represents all difference values from 97 to 255.

On reconstruction in the Decoder, the 31 transmission codes can be expanded back to only 31 different values. The difference value expansion for any particular transmission code is the mean of the distribution of the statistical occurrences of the difference values originally lumped together in one transmission code.

In the compression/expansion process, DPCM errors are introduced into the reconstructed samples. Their effect is subjectively slight but takes the form of 'edge busyness' and 'granular noise' common to many DPCM schemes.

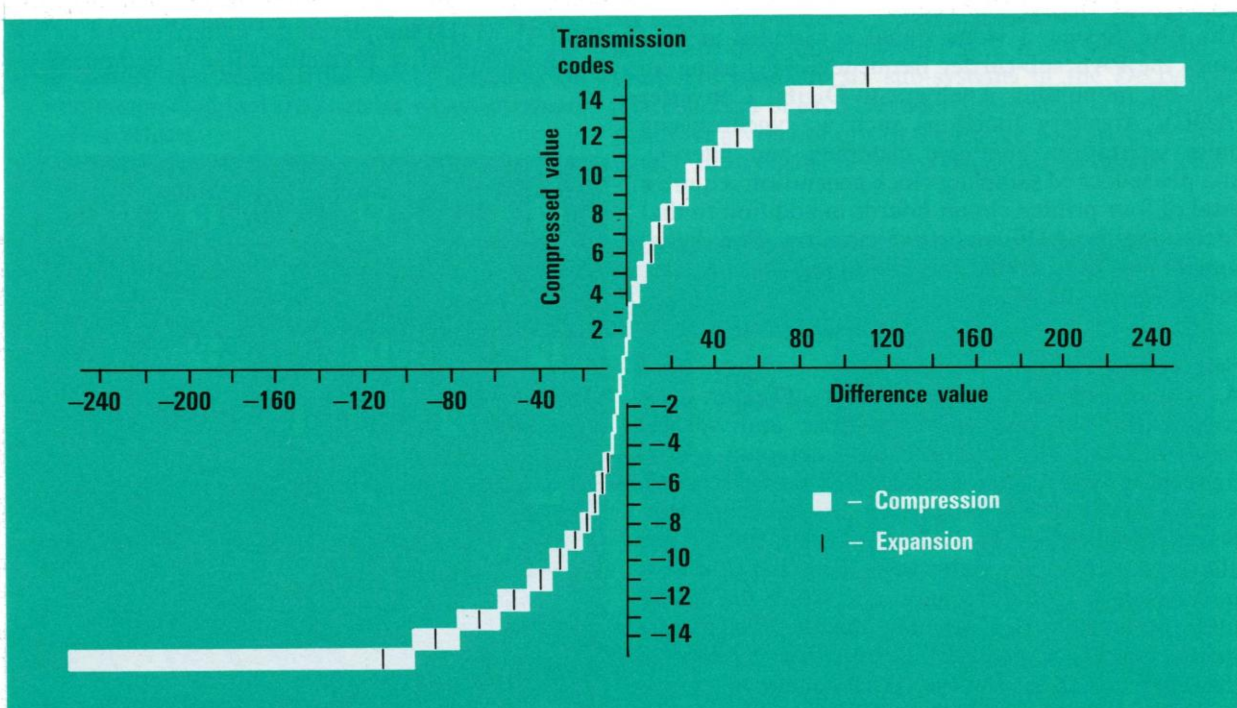


Fig. 4. The compression and expansion values used for coding the difference value.

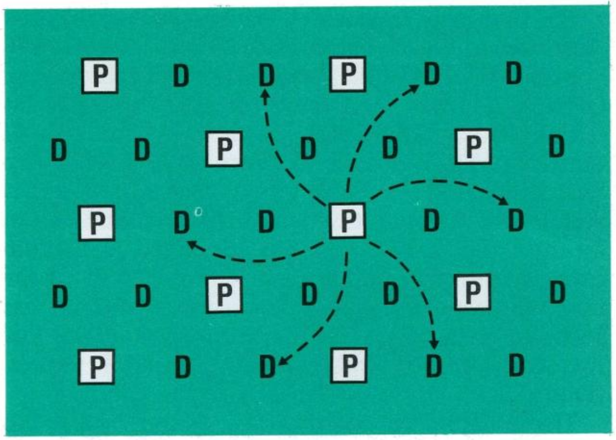


Fig. 5. The propagation of errors from a PCM word error.

Error Protection

The PCM and DPCM samples in the output from the bit-rate reduction sub-system are very different signals and are best given differing forms of error protection.

Each unmodified PCM sample will be used in the reconstruction of six DPCM samples in the Decoder. A bit error in a PCM sample is spread, therefore, to a total of seven samples in a hexagon (Fig. 5). The pattern of errors is converted in the Decoder to an analogue error signal rich in sub-carrier frequency, and the resulting 'snowflake' will often be of highly saturated colour. It is important, therefore, to *error correct* PCM bits whenever possible. On the other hand, a bit error in a DPCM sample does not spread to surrounding samples. The value of a DPCM sample thought to be in error is statistically most likely to have been zero. The technique of *error concealment* can be applied to erroneous DPCM samples, therefore, by simply replacing them by the value zero.

Both the PCM and DPCM samples are protected by using Wyner-Ash (8, 7) forward error correction coding (Wyner-Ash[3]), implemented in quite different ways (see Fig. 6). In the case of PCM samples, a single bit error correction is provided for the most significant seven bits. The bit-rate overhead is $12\frac{1}{2}\%$, accounted for by one bit for each eight-bit word. For DPCM words, parity bits for groups of seven words are calculated and themselves applied to a Wyner-Ash decoder. A single Wyner-Ash parity bit is created for

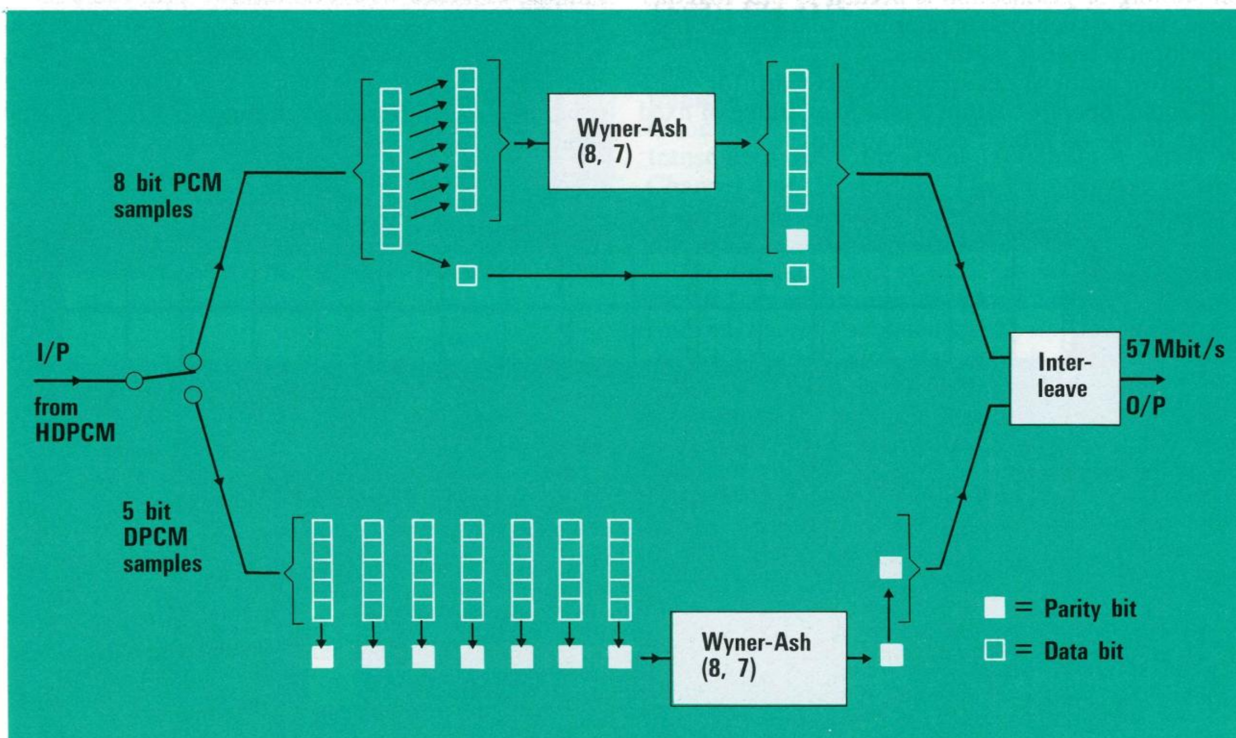


Fig. 6. Error protection coding for PCM and DPCM inputs.

each seven DPCM words, and this parity bit alone is transmitted with the 35 DPCM bits. In the Decoder, the DPCM word parity bits are recreated and a Wyner-Ash error correcting decoder is applied to them and to the received Wyner-Ash parity bit. Any single bit error in the group will be located as far as the DPCM word in which it occurs. By replacing the whole erroneous word with zero, error concealment will be effected. The total bit-rate overhead for error protection is 3.8 Mbit/s giving a final processed video signal of 57 Mbit/s.

Asynchronous Multiplexing

The video serial bit stream following error protection is at precisely $90/7 \times f_{sc}$ bit/s. The tolerance in this rate is obviously proportional to the sub-carrier frequency variation allowed within the PAL specification (± 1 Hz within the UK and ± 5 Hz between countries) which becomes ± 13 bit/s inland or ± 65 bit/s between countries.

There are also strictly defined tolerance limits specified for the audio signal rate [2,048 kbit/s $\pm$ 50 parts per million (ppm)] and the outgoing digital modulation rate (60 Mbit/s $\pm$ 15 ppm). A process of bit stuffing or justification is needed to link together these three asynchronous rates and to allow for their individual tolerance variations.

Positive justification, separately provided for video and audio, operates within a multiplex frame of fixed length in the 60 Mbit/s output stream.

The multiplex frame of 1,792 bits is assembled as illustrated in Fig. 7. The construction is shown as 896 symbols of two parallel bits since the interface to the QPSK modulator is in the form of two parallel bit streams at 30 Mbit/s each. Each frame contains 12 Start bits, 12 Justification Control bits, 1,700 Video bits, 4 Video Justification bits, 60 Audio bits and 4 Audio Justification bits. At nominal input and output bit-rates the Justification bits for video and audio carry dummy information for 0.37 and 0.71 of the time respectively. These figures are known as Justification Ratios and are chosen to minimise low frequency jitter in the Decoder system clock signals. (Duttweiler[4]).

The processing which the video signal has undergone in the HDPCM and error protection sub-systems contributes somewhat towards randomising its spectral content. A psuedo-random scrambling sequence imposed upon the multiplex frame completes the randomising. This provides an energy dispersed transmission signal with characteristics approaching those of white noise, so ensuring rapid recovery of carrier and clock in the QPSK demodulator following interruption of the transmitted signal. The psuedo-random sequence would naturally repeat every 2,047 bits ($2^{11}-1$) but is prematurely reset every 1,792 bits in synchronisation with the multiplex frame. This method of scrambling avoids the error extension produced by self-synchronising types. The final scrambled digital output signal is presented to the

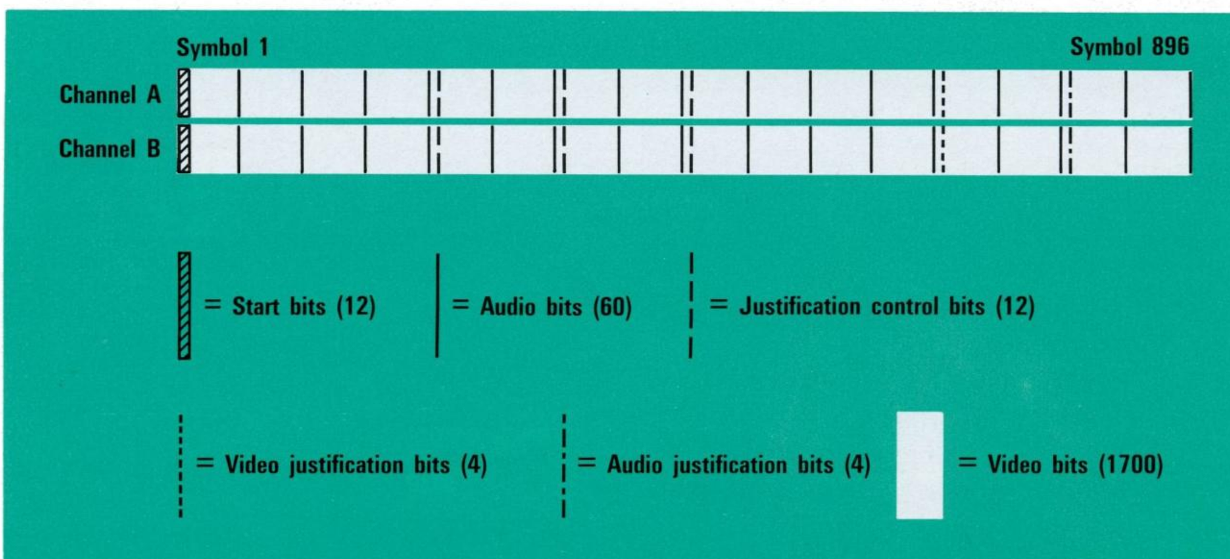


Fig. 7. The multiplex frame used for the 60 Mbit/s output stream.

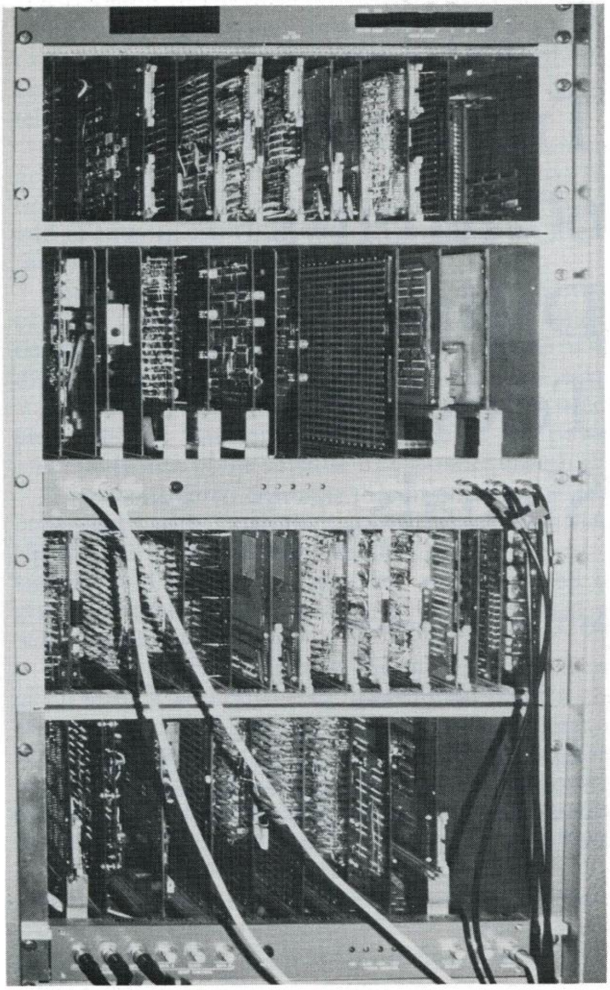


Fig. 8. The 60 Mbit/s digital Video Codec.

QPSK modulator as two 30 Mbit/s parallel streams accompanied by a 30 MHz clock.

The Decoder

Most of the sub-systems of the Decoder perform reciprocal functions of the Coder sub-systems. In addition, error counting circuitry is included to provide a measure of the total bit error ratio on the satellite link. During the practical tests the pseudo-random test signal replaced the 2,048 kbit/s audio signal, and the error counter continuously compared the received sequence with a locally generated error-free sequence. In normal operation the multiplex frame alignment and error correction sub-systems provide output signals to the error counter to give an indication of detected bit errors.

There is a fourfold ambiguity in the phase of the carrier signal in the QPSK demodulator which is resolved in the burst mode telephony case by using differential encoding and decoding. This doubles the bit-error ratio and also requires that the error correction system shall cope with bursts of up to four errors. The tests, conducted by the IBA, used absolute encoding (no differential encoding) and resolved the carrier phase ambiguity by recognising incorrect decoding of the multiplex frame start-word, and by stepping on the carrier recovery phase-locked-loop until correct decoding was achieved.

Hardware

During the design procedure much flexibility was built into the indivudual sub-units, and extra circuitry was included to assist servicing and fault locating. The resulting protype equipment, constructed by using a mixture of printed circuit and wire wrap boards, is shown in Fig. 8. It occupies in total about 1 m of rack space.

TESTS VIA OTS

During two periods of 1980, tests of the Codec were conducted via OTS. In April the Coder was transported to the British Telecom Earth Station, Goonhilly Down, Cornwall, and signals were transmitted from the 19 m Goonhilly 4 aerial via Channel $\bar{4}$ of the satellite. The Decoder was situated at the IBA, Crawley Court, Hampshire, and received the signals via the 3 m fixed earth station dish aerial.

The second period of tests was in July 1980, using the IBA transportable up-link (2.5 m dish aerial) for transmission of the coded signal, and again receiving on the 3 m fixed earth station dish aerial.

In both cases excellent error-free pictures were received, and link performance under simulated conditions of fading and interference was examined in detail. The results are presented elsewhere in this volume (Hopkins[5]).

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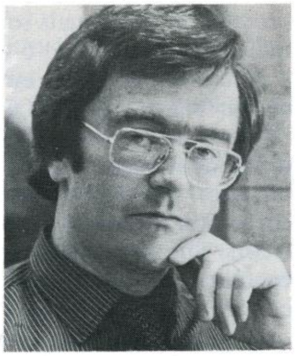
In 1979 he joined the Radio Frequency Section of the IBA where his interests include all aspects of satellite broadcasting.
In his spare time he enjoys cycle racing, running and mountaineering.



Satellite Transmission of 60 Mbit/s Digital Television Signals

by D. K. W. Hopkins

Synopsis
This chapter describes a series of test transmissions of 60 Mbit/s digitally coded PAL System I television signals using the OTS.

Various aspects of the QPSK modulation system and the satellite channel used are considered, and results of transmission measurements are presented.

The results of subjective tests of the system are given and a comparison is made between digital television transmission and analogue FM television transmission by satellite.

Within the last decade there has been a massive expansion in digital technology, and the transmission of information in digital format has become almost commonplace. At the same time geostationary telecommunication satellites have been carrying an increasing volume of both international telephony traffic and television programmes. At present most of the telephony traffic within the INTELSAT network is transmitted in analogue format using Frequency Division Multiplex/ Frequency Modulation (FDM/FM). In the future, satellite telephony traffic will increasingly be transmitted digitally, using Time Division Multiple Access (TDMA) with digital modulation.

The forthcoming European Communication Satellite (ECS), for which the OTS is the flying test-bed, will carry telephony traffic using TDMA with Quarternary Phase-Shift Keying (QPSK) modulation, at a bit-rate of 120 Mbit/s in 80 MHz bandwidth transponders.

By contrast, the INTELSAT system is expected to employ a similar multiple access and modulation system but with a bit-rate of 60 Mbit/s in 40 MHz transponders.

Broadcasting organisations are giving increasing attention to the satellite transmission of television signals, for Direct Broadcast, for point-to-point distribution and contribution, and for Electronic News Gathering (ENG) applications. It is anticipated that digital processing will be employed increasingly in studios and that video signals will in due course be distributed in digital form. Only where such signals are to be transmitted on existing terrestrial facilities will they be converted to an analogue form.

In 1980, the Experimental and Development Department of the IBA performed a series of

experimental test transmissions of a 60 Mbit/s PAL composite coded digital television system using the OTS, in order to investigate the technical problems associated with the coding and transmission of digital television signals by satellite.

These tests were performed with the co-operation and assistance of British Telecom who provided the up-link transmission facilities at Goonhilly, Cornwall, and of Interim EUTELSAT who arranged the use of the OTS.

In planning this test programme the question arose of what transmission bit-rate to use. It was clearly desirable that the modulation be compatible with digital telephony traffic, so that conventional earth station digital transmission facilities could be used; also, that the transmission should utilise the power and bandwidth of the satellite transponder effectively.

It was considered desirable to minimise the bit-rate consistent with maintaining 'broadcast quality' signals and it was determined that a PAL television signal could be digitally encoded and processed to give an overall bit-rate of about 60 Mbit/s consistent with this quality.

The reason for minimising the bit-rate is that, for given up-link and down-link transmitted powers, the required figures of merit (G/T) and hence the costs of the satellite receiver and the ground station receivers are proportional to the bit-rate. It was therefore decided that 60 Mbit/s transmission with QPSK modulation should be used for the experimental tests.

QPSK modulation is currently specified for satellite digital telephony transmission in the proposed EUTELSAT and INTELSAT TDMA systems. Much effort has been and still is being applied, in relation to these systems, to determine the best form of digital modulation for satellite channels. Several contending modulation systems exist; however, from work so far conducted, QPSK has proved the optimum choice.

The main purpose of the experimental programme at the IBA was to investigate the technical parameters associated with the coding and transmission of digital television signals via satellite. Particular interest was attached to the satellite transmission aspects, and to the problems of asynchronously multiplexing the digital video and audio channels into a continuous 60 Mbit/s bit stream. It was also necessary to compare the technical and other parameters of digital and conventional analogue FM transmission of television signals via satellite. Therefore, a Video Codec was specially designed and constructed[1], a 60 Mbit/s QPSK TDMA telephony (burst mode) modem was acquired and modified for use in continuous mode and a special down-converter compatible with this digital system was designed and added to the Crawley Court 3 m satellite receiver.

The digital television signals were transmitted to the OTS from the British Telecom earth station at Goonhilly Downs, Cornwall, and also from the IBA transportable up-link located at Crawley Court. Figure 1 shows the configuration of equipment for the tests. A total of seventeen days of transmission via the OTS were used.

QPSK MODULATION

Phase-shift-keying modulation is a digital modulation system in which the data signals switch the carrier phase between various discrete and equi-spaced values. In the case of QPSK, the carrier phase assumes one of four values spaced by $\pi/2$ radians at the centre of the symbol period. It is important to appreciate that the QPSK specified for satellite channels is in fact an amplitude modulation process, and that both the instantaneous carrier envelope and the carrier phase are functions of time. Only at the centre of the symbol period does the phasor, describing the signal, pass through the specified points (and then only in the absence of any distortion in the channel). A brief description of QPSK transmission has been given by Drury[2].

The particular form of channel filters employed in the QPSK modulator and demodulator influences the performance of the PSK modulation system, particularly in a satellite channel where the Travelling Wave Tube Amplifier (TWTA) in the transponder is normally operated near saturation. Much effort has been expended by various organisations in efforts to determine optimum channel filters for the European ECS and INTELSAT TDMA telephony systems; however, at the time of this experimental programme, no 'standard' optimum filter had been agreed. The filters used in the IBA tests result in a so-called '50% cosine roll-off' channel.

Identical 'root 50% cosine roll-off' filters were employed in the modulator and demodulator. These filters implement a Nyquist channel due to the odd (i.e. cosinusoidal) symmetry of the cascaded transmitter and receiver filter amplitude responses about the Nyquist frequency, in this case equal to 15 MHz. Figure 2 shows the modulus squared of the frequency response of one of these filters.

In the absence of distortions in the channel, such a scheme results in a 'matched receiver' and zero intersymbol interference; this combination results in

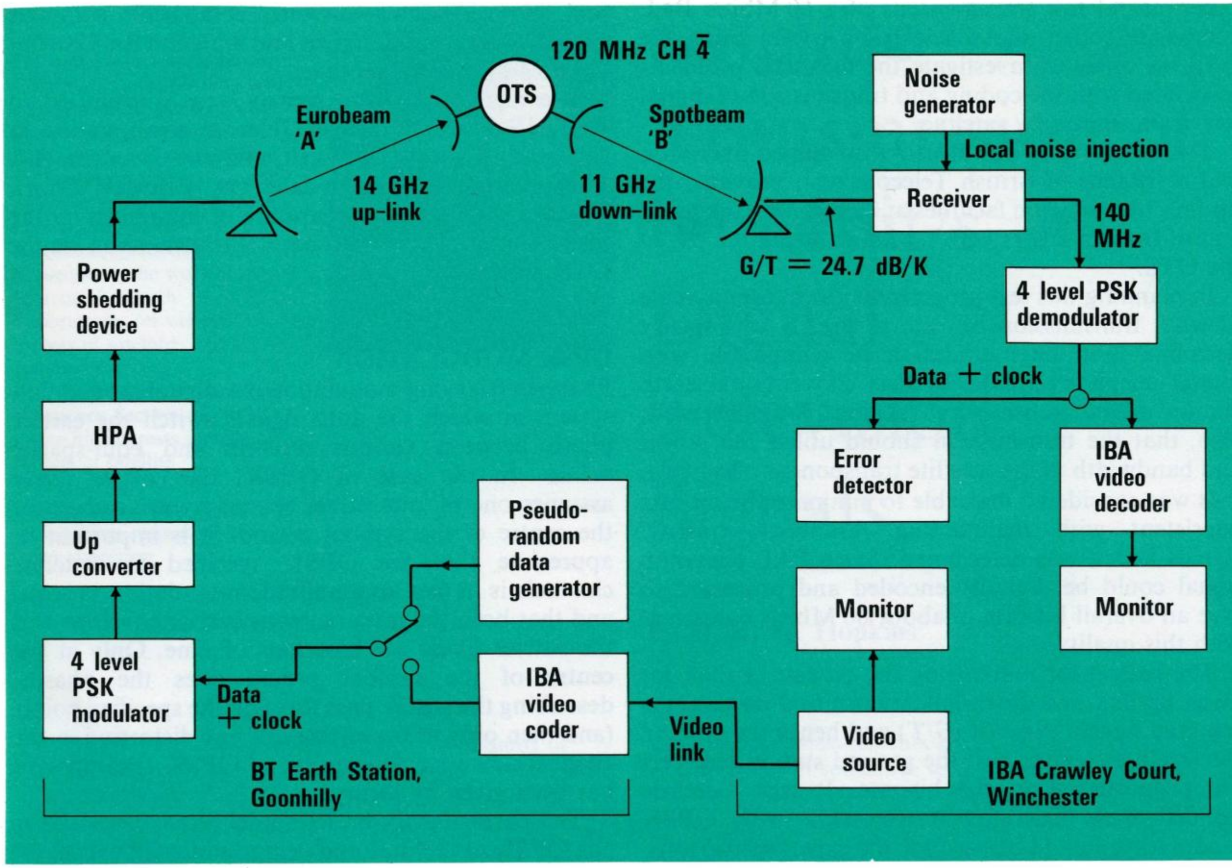


Fig. 1. The general equipment configuration for the IBA/BT digital television tests.

optimum detection efficiency at the receiver, in the sense that the bit-error probability for any given received signal-to-noise power density ratio is minimised. This filtering scheme is that currently specified for the proposed ECS TDMA–QPSK system. A roll-off factor of 50% is believed to result in near optimum signalling for a saturated satellite channel. At the demodulator regenerator output, the bit error probability for this QPSK system in an ideal linear channel is given by:

$$Peb = \tfrac{1}{2}\,\text{erfc}\left(\frac{Eb}{No}\right)^{\frac{1}{2}}$$

where erfc (x) is the complementary error function, the values of which are normally obtained from published tables: $Eb = C/R$ where Eb is the received energy per bit (J).
C is the received carrier power (W)
R is the bit-rate, (bit/s)
and No is the thermal noise spectral density (W/Hz).

The noise power spectral density is assumed to be constant across the received signal bandwidth (the usual case in practice).

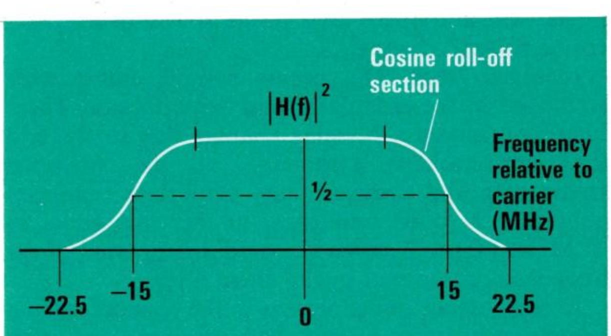


Fig. 2. The 50% cosine roll-off filter response.

The bit-error ratio (BER) is defined as:

$$\text{BER} = \underset{N\to\infty}{\text{Limit}} \frac{\text{Number of bits in error in } N \text{ bit sequence}}{N}$$

and is numerically equal to *Peb*.

Demodulation of the QPSK signal requires a carrier phase reference at the receiver. This phase reference is established by the carrier recovery system in the demodulator, but this reference is subject to an inherent fourfold $\pi/2$ ambiguity unless special action is taken. To obviate this, the data is often differentially encoded at the modulator so that the information resides in the data transitions. This is called a 'differentially encoded' system whereas the uncoded system is referred to as 'absolute encoded'. The penalty associated with differential encoding is that single symbol errors become extended over two symbol periods and the BER is approximately doubled. Figure 3 shows the BER as a function of Eb/No for an ideal system in a linear channel. Using 50% cosine roll-off filters it can be shown that the transmitted 60 Mbit/s QPSK signal has 99% of its power within a 38 MHz bandwidth. This corresponds to a spectral utilisation factor of 1.58 bit/s/Hz.

SATELLITE LINK POWER CONSIDERATION

The 60 Mbit/s QPSK signals were transmitted through the OTS 120 MHz transponder channel $\bar{4}$. The satellite therefore received its signals on the Eurobeam 'A' antenna at 14 GHz and transmitted on the Spotbeam 'B' at 11 GHz, in both cases using linear polarisation.

It was necessary to use the 120 MHz transponder rather than the 40 MHz transponder with which the 60 Mbit/s QPSK signal is bandwidth compatible. This was because the effective isotropic radiated power (e.i.r.p.) transmitted in the direction of Crawley Court by the 40 MHz transponder is some 8 dB lower than that of the 120 MHz transponder, while the parameters of the down-link are such that only the 120 MHz transponder gives a positive fade margin.

The down-link parameters have the major influence on the system performance. The increase in system noise level due to up-link noise is estimated to be only about 0.2 dB with the TWTA saturated and the satellite transponder gain set to its nominal value. The down-link parameters are summarised in Table 1.

The important parameter defining the system performance is the received carrier power-to-noise density ratio:

Table 1: OTS CHANNEL $\bar{4}$ CRAWLEY COURT 3-m RECEIVER DOWN-LINK PARAMETERS

Transmitted power	$P_T = 11.9$ dBW
Spotbeam 'B' gain (London)	$G_T = 33.5$ dB
Free-space loss 11 GHz	$A = 205.5$ dB
Receiver 'Figure of merit'	$G/T = 24.7$ dB/K

$$\frac{C}{No_{\text{Down}}} = P_T + G_T - A + \frac{G}{T} - 10 \log k$$

where k = Boltzmann's constant ($10 \log k = -228.6$ dBK).

By inserting the indicated values from Table 1 the downlink C/No ratio is evaluated to be 93.7 dBHz.

In practice, it was found that the values of C/No obtained throughout the transmission tests were very close to this predicted value. Changes in the value of C/No with time are to be expected, primarily due to atmospheric attenuation and some such changes were indeed observed during the tests. Throughout the transmission tests the value of C/No was measured many times. The maximum value measured was 93.8 dBHz and the minimum 91.2 dBHz. This maximum value agrees very well with the predicted 'free-space' value of 93.7 dBHz; while, for the minimum value, it can be concluded that a down-link fade of some 2.6 dB was occurring at the time of measurement. This excellent agreement with the predicted value demonstrates that there is very little uncertainty in the free-space down-link power budget for satellite systems. However, in planning an operational system, for which certain link availability figures must be attained, a major uncertainty will be the statistics of atmospheric path loss; and, in a frequency re-use system, to depolarisation effects. (See, for example, O'Neill and Hayter[3].)

SATELLITE CHANNEL PERFORMANCE

One of the advantages of digital transmission systems is that the transmission channel is 'transparent', except for the unavoidable occurrence of bit errors due to thermal noise. Analogue impairments for television transmission, such as differential gain and phase, do not accumulate in purely digital systems. Moreover, in a satellite channel, since bit errors are due to thermal noise only, individual errors are statistically independent; and, consequently at low bit

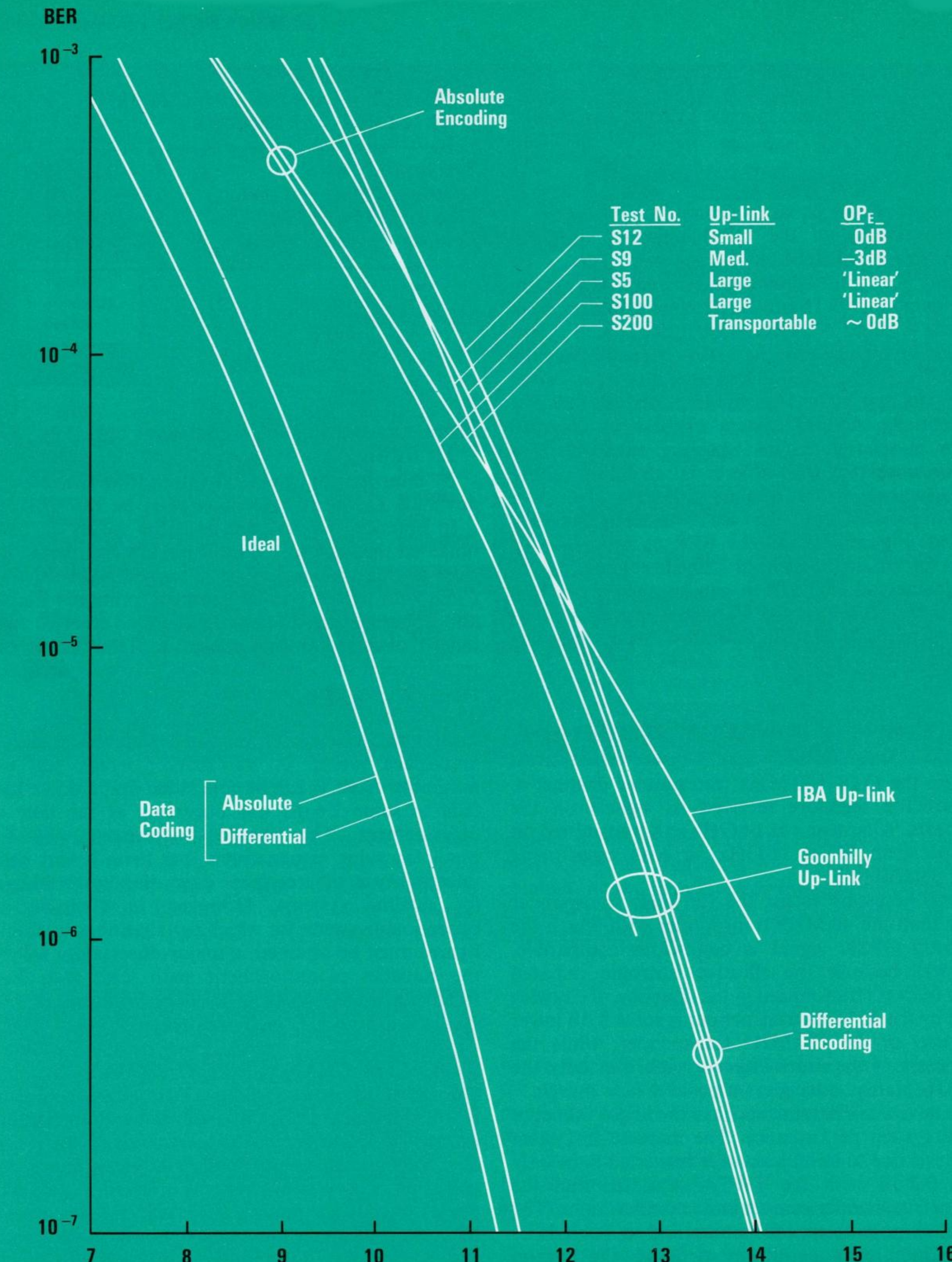


Fig. 3. The results of transmission tests at 60 Mbit/s.

error ratios (the digital television system described here is designed to operate at a BER less than about 1×10^{-5}), the errors are predominately single and isolated. There is no occurrence of the burst of errors commonly experienced for instance in digital line transmission systems due to non-thermal noise interference. This means that the satellite channel performance can be assessed by using suitable digital test signals. The test signals used were pseudo-random bit sequences (PRBS). By comparing the received PRBS, corrupted by bit errors, with a locally generated identical PRBS, the bit errors can be identified and the BER evaluated.

It is necessary that the link performance be assessed over a range of values of Eb/No. Since the satellite link noise is purely due to thermal sources, it is valid to simulate different noise levels by artificially adding white thermal noise from a noise generator to the received signal as indicated in Fig. 1. The value of Eb/No was measured at the receiver output.

Figure 3 shows some of the transmission test results, in the form of the BER plotted as a function of Eb/No. In these transmission tests the satellite link performance was evaluated for several values of High Power Amplifier (HPA) operating point with respect to saturation output power (OP_E). This was achieved in the case of transmissions from Goonhilly by setting the required value of OP_E and 'losing' excess power output in a 'power shedder' (see Fig. 1). Three values of OP_E were used, 0 dB corresponding to saturation, -3 dB, and -10 dB corresponding to (almost) linear operation. For each value of OP_E, an optimum satellite TWTA operating point was derived by use of a specific measurement procedure. The optimum value demonstrates the balance between an increased BER, as the output power is increased, due to distortion, and an increased BER as the output power is reduced, and the received Eb/No is thereby reduced. In all three cases, the optimum TWTA operating point was found to be within 0.5 dB backed-off from saturation. The graphical results shown in Fig. 3 apply at the previously determined optimum operating points.

Both absolute and differentially encoded systems were tested. For each of these, a different demodulator configuration was employed. In the case of absolute encoding, the required absolute carrier phase reference was established by determining whether the received data had the correct sense, and slipping the carrier phase reference by $\pi/2$ radians until the correct data sense was obtained. The results shown in Fig. 3 for differential encoding indicate a somewhat greater increase in BER, compared to those for absolute encoding at 'high' BER, than the two-fold increase expected. This was due to an instrumental problem in the QPSK demodulator which was not present in the absolute encoded configuration.

In general, the results show that the system performance is relatively insensitive to the earth station operating point. With transmission from Goonhilly at a BER equal to 1×10^{-5}, an Eb/No ratio about 2 dB in excess of the ideal value is required. The difference between the required and the ideal value of Eb/No is termed the 'degradation' and is usually expressed in dB. This degradation from ideal is due to the distortion caused by the earth station HPA, the satellite TWTA, and to imperfections in frequency responses throughout the system (e.g. amplitude response errors and non-zero group delay in filters). Determination of the system degradation is particularly important, since the designers of future satellite links will use these figures in the planning stage.

Unfortunately, analytical techniques are insufficient for readily calculating the degree of degradation, and recourse to measured values becomes necessary. Further degradations can result from co-channel and adjacent channel interference.

Figure 3 shows that, using absolute encoding, with transmission from Goonhilly at a BER equal to 1×10^{-5}, which was the BER used in planning the link, the Eb/No ratio required is about 11.7 dB, i.e. 2.1 dB in excess of the ideal value 9.6 dB. This corresponds to a C/No value of 89.5 dBHz which compares with the maximum value of C/No obtained of 93.8 dBHz. There is, therefore, about 4.3 dB down-link fade margin at 1×10^{-5} BER for these conditions on the Crawley Court receiver.

With transmission via the IBA transportable up-link (see Fig. 3) there is some increased degradation compared to transmission from Goonhilly, when using the same conditions at low BER. This is attributed to an increase in intersymbol interference (ISI) due to certain imperfections in the up-link. In an operational system, this defect would be unlikely to arise.

Energy Dispersal

The demand for radio frequency spectrum is so great that every possible technique for avoiding interference between different networks is employed. The effects of interference are generally less if the interfering energy is distributed throughout the frequency band used rather than concentrated within any small portion of

that band. An unmodulated carrier signal would represent the worst condition. Therefore, current regulations relating to the interference caused by space systems specify maximum power flux densities in a 4 kHz bandwidth.

The energy dispersal factor '*D*' provides a measure of the dispersal effectiveness of a particular modulation system. It is defined as:

$$D = 10 \log_{10} \frac{\text{Total power}}{\text{Maximum power per 4 kHz}} \text{ dB}$$

The dispersal factor of a digital system of this form is minimised when the data signals are random, the statistical mean of the data elements is zero, and the individual data elements are uncorrelated. In the IBA experimental 60 Mbit/s system, these conditions are largely satisfied; a scrambler is employed in the video coder (Wilson[1]) to ensure this. The dispersal factor D for a 60 Mbit/s QPSK system of the type described can be shown to have an ultimate value of 38.7 dB. The dispersal factor was also measured and found to be 37.5 dB. Within the limits of measurement error this is essentially equal to the predicted value.

Video Signal Quality

The impairments to a digital television signal arise from two main causes: the impairment inherent to the video coding algorithm, and the effects of bit errors occurring in the transmission channel. In this experimental system the coding impairment is very small, and probably only expert viewers would detect it at all. Considerable reductions in the effects of transmission channel bit errors are made in the video codec due to the employment of forward error correcting coding and an error concealment technique (Wilson[1]).

The subjective impairment due to transmission bit errors was evaluated by injecting thermal noise into the channel, connected in an IF loop configuration, thereby causing random bit errors. Observers scored the impairment due to these bit errors according to the CCIR Recommendation 500, 5-point impairment scale. The results in Fig. 4 show that impairments became 'just perceptible' (about 'Grade 4.5' impairment) at a transmission BER of 3×10^{-5}, while the 'threshold' BER which caused an impairment value of 2 (annoying) was 1×10^{-3}. From the results of test number S100 shown in Fig. 3 it can be seen that

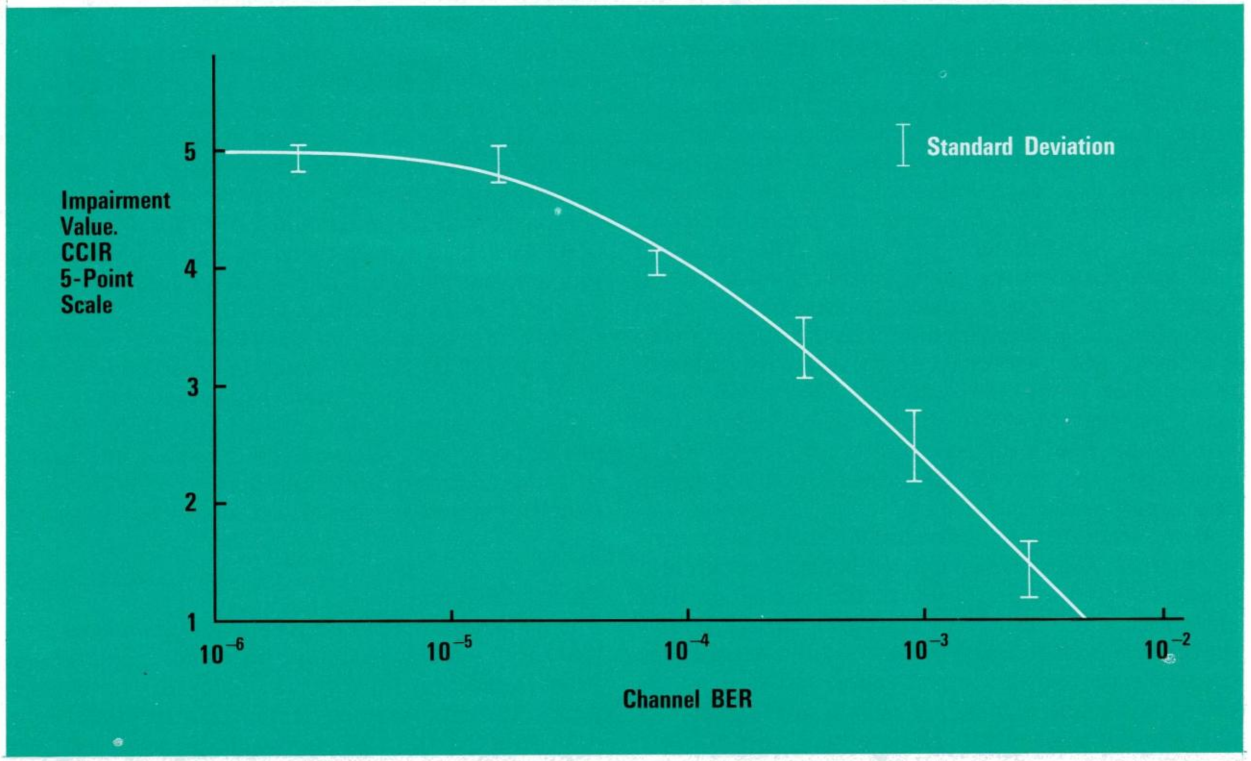


Fig. 4. Subjective evaluations of the impairment due to bit errors.

the value of Eb/No for a 'just perceptible' impairment is 11 dB(C/No = 88.7 dBHz) and that for 'threshold' conditions it is 8.4 dB (C/No = 86.2 dBHz).

COMPARISON BETWEEN DIGITAL AND FM TRANSMISSION OF TELEVISION SIGNALS VIA SATELLITE

Television signals are currently transmitted via satellite using analogue frequency modulation. For point-to-point transmission of television signals via satellite, i.e. not direct broadcasting, the deviation constant and the bandwidth have been standardised at 25 MHz/V and 36 MHz respectively. This bandwidth is essentially the same as the 99% power bandwidth of the IBA 60 Mbit/s QPSK signal (38 MHz).

It is of interest to compare the C/No requirements for the FM and digital systems. In tests of frequency modulation television transmission with these parameters using the OTS 120 MHz transponder it was found that, for a 53 dB video signal-to-noise ratio (unified weighting) which corresponds approximately to 'Grade 4.5' impairment, a C/No value of 91.6 dBHz was required. Conventionally, the FM threshold is assumed to occur at a carrier-to-noise power ratio of about 11 dB, corresponding to a C/No value of 86.6 dBHz. At threshold, the picture will be almost unusable (though the possibility of reducing the threshold effects by using 'threshold extension' demodulators must be acknowledged). The picture quality obtained at this conventional 'threshold' C/No value could be compared with that obtained at the 'threshold' BER for the digital system with an error rate of 1×10^{-3}. Comparison is very difficult since the subjective effects of FM noise and digital errors are entirely different. Nevertheless, the 'just perceptible' and 'threshold' values of C/No for the FM system can be taken as being of the order of 91.6 and 86.6 dBHz respectively. These compare with the values of 88.7 and 86.2 dBHz for the 'just perceptible' and 'threshold' values of C/No for the digital system.

The energy dispersal factor for frequency modulated television signals of this form is estimated to be about 28 dB, i.e. 9 dB less than that of the digital television system described. The excellent energy dispersal factor of the digital system is of special advantage where the transmitting earth station uses a 'small' aerial of the order of 3 m diameter, such as has been used for mobile and/or transportable satellite up-links. With a small up-link dish aerial the transmitted power has to be relatively high in order that the radiated e.i.r.p. is equal to the value required to saturate the satellite. The side-lobe radiation, which has the potential of interfering with other services, therefore has a lower value (some 9 dB less per 4 kHz) for the digital system than that of an FM system, operating at the same up-link e.i.r.p.

Therefore, it can be seen that for satellite transmission of television signals, a digital system can offer distinct advantages over analogue FM systems. Moreover, the digital system is estimated to be more tolerant to interference than the FM system. These advantages are obtained at the expense of considerably greater equipment complexity. The FM system requires no source coding equipment, whereas the digital video codec is a complicated and expensive item. Also, a QPSK modem is somewhat more expensive than a simple FM modem. However, as a percentage of the total cost of transmitting and receiving ground stations the differences are likely to be small.

ACKNOWLEDGEMENT

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A biographical note appears on page 28.

A Receiving System using Adaptive Cancellation to reduce Cross-polar Interference in Dual Polarisation Satellite Links

by H. J. O'Neill and B. V. W. Isaacs

Synopsis
The potential capacity of satellite links can be extended by employing frequency reuse. One technique uses dual orthogonal polarisations. At the frequencies used in modern systems, however, atmospheric precipitation reduces polarisation purity. This chapter describes an improved adaptive system to cancel such cross-polarisation and so maintain channel isolation. Control voltages derived from signals from the satellite are arranged to drive a cross-coupling network between the channels in the receiver, so as to cancel the unwanted cross-polar signal appearing in the wanted channel. A system of this type was tested using TV transmissions from the European Orbital Test Satellite (OTS) and successful cancellation was obtained.

Channel capacity in satellite communication systems can be considerably extended by employing techniques of frequency reuse. Two methods are generally adopted; one achieves isolation between channels by employing spatial discrimination of beam coverage areas. The other method, the subject of the experiments described in this chapter, uses orthogonal polarisations of the transmitted signals: one wideband channel is transmitted on, say, vertical polarisation, while the second occupying the same frequency band, is transmitted on horizontal polarisation. The required isolation is obtained by the

cross-polar discrimination of the aerial systems. To maintain this isolation at the necessary high level the satellite and ground station aerials must be carefully designed and oriented. Some form of polarisation tracking is nevertheless required to overcome the effects of ambient temperature on the aerials and of satellite station-keeping errors; if this tracking is accomplished by mechanical means, the cost can be considerable.

An additional unwanted effect is depolarisation of the signals by atmospheric precipitation in the propagation path. In heavy rainstorms channel isolation can be reduced to 10 dB (or worse); interference at this level is clearly unacceptable.

The unwanted coupling between the channels can be reduced by employing a cancellation technique, in which a fraction of the signal is coupled from each channel and then added to the other channel at a level equal in amplitude and in antiphase to the unwanted cross-polar component.

An adaptive cancellation system based on the use of a complex attenuator is described in this chapter. Two methods of determining the degree of coupling between the channels, for use as error signal, have been investigated. One uses pilot tones transmitted with the original signals. The second uses correlators. Both methods were tested when TV transmissions took place from the OTS.

CROSS-POLAR CANCELLATION

A diagrammatic representation of a cross-polar cancellation system is given in Fig. 1. Cross-coupling is introduced between the channels by the two complex attenuators (CA in the diagram) and the control voltage is so arranged that the cross-coupled signals are equal and opposite to the original cross-coupling in the transmission path as shown. If the coupling factors K_1, K_2 in Fig. 1 are small then their product $K_1\ K_2$ can be ignored in the outputs, leaving the original signals clear of interference.

If the system is to adapt to the changes in cross-polar coupling which occur in a practical system, some means of detecting this coupling must be provided. Figure 2 is a block diagram of a system in which a pilot tone transmitted with the original signal is used as a measure of cross-polar coupling. The CW pilot tone is transmitted with the interfering signal at a frequency separation determined by the bandwidth of the complex attenuator. The pilot-tone receiver itself can be of narrow bandwidth and is arranged to provide a d.c. output determined by the cross-polar level of pilot tone at its input. This d.c. is fed as an error signal to the complex attenuator via a feedback loop as shown. The action of the loop is to suppress the cross-polar level of the pilot tone by adjusting the complex attenuator. Since the complex attenuator is broadband the interfering signal appearing on the

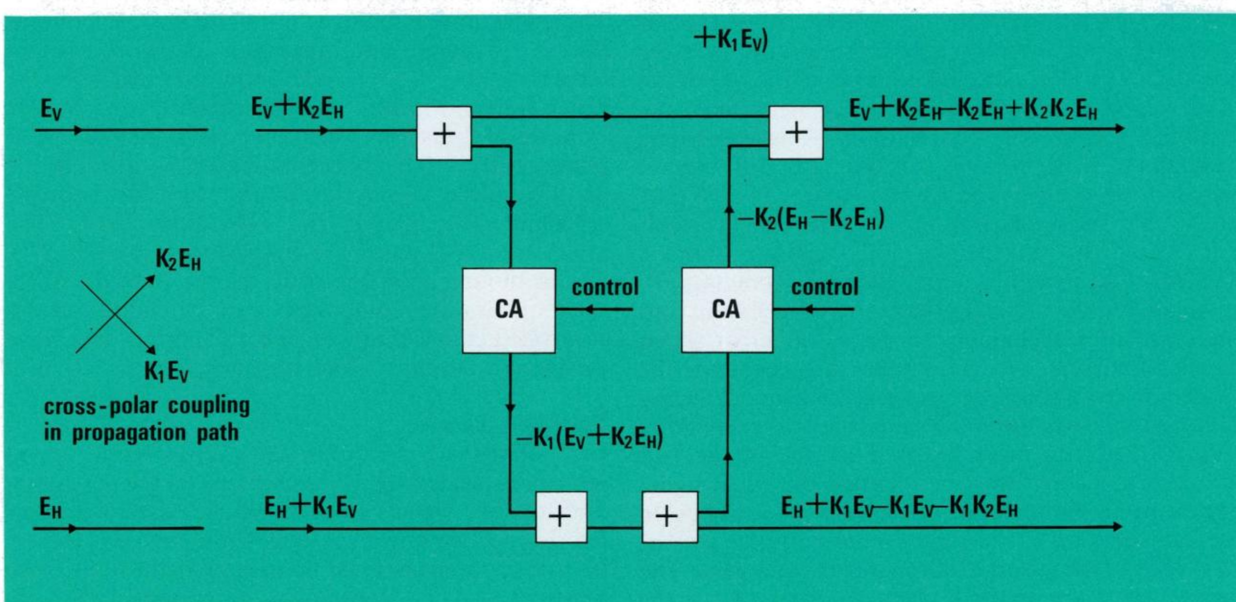


Fig. 1. A cross-polar cancellation system.

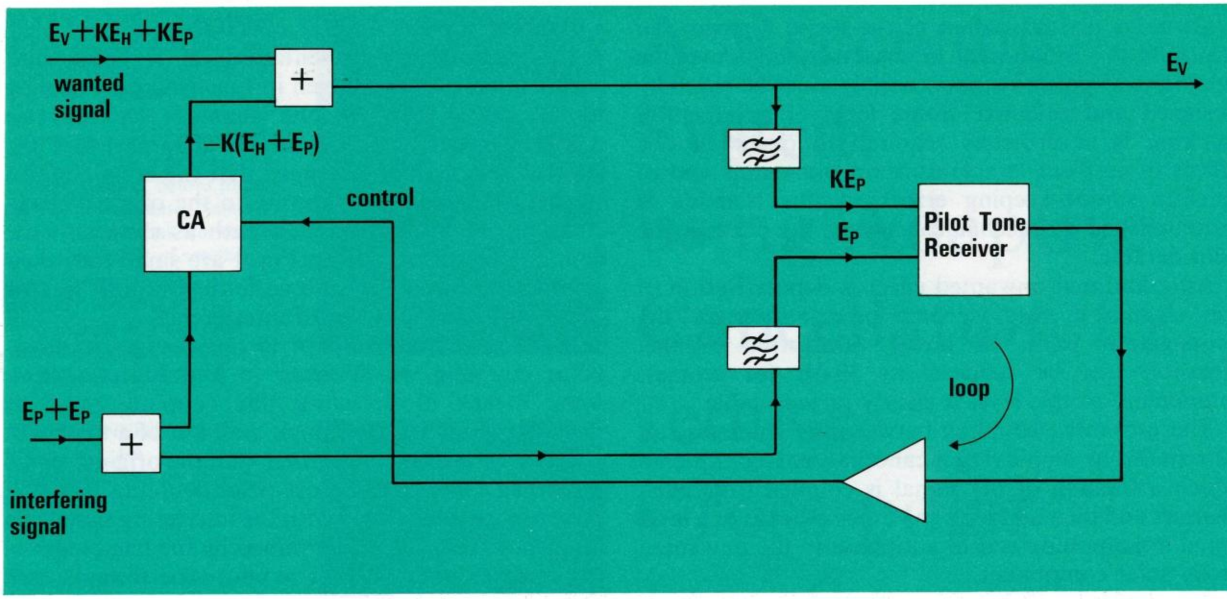


Fig. 2. An adaptive cancellation system which uses a pilot tone.

same polarisation as the pilot tone will also be suppressed. For cancellation of a dual channel system two pilot tones are required.

In theory, if the pilot tones are inserted at the ground transmitting stations, the total system cross-polarisation (i.e. both up-link and down-link) can be cancelled. In practice, however, non-linearities in the TWTA of the satellite (which is operated at saturation) will cause intermodulation and limit the effectiveness of the cancellation. One of the objectives of the present investigation is to determine the feasibility of up-link cancellation using pilot-tone techniques. It is possible to use onboard beacon signals from the satellite as pilot tones. In this case down-link cross-polarisation only, can be cancelled; this would be worthwhile for receiving stations located in areas with wet and thundery climates.

An alternative method of adaptive cancellation is to use correlation techniques to derive the error signal for the feedback. No pilot tones are required, the degree of cross-coupling between the channels being obtained by correlating the signals in two correlators (Fig. 3). Limiters must be used in one of the two inputs to the correlators to suppress the small signal appearing in the presence of the larger one. Thus, in the case of loop 1, the inputs to the limiter will be $E_V+K_1E_H$ and to the correlator $E_H+K_2E_V$. The limiter will suppress the K_1E_H term leaving E_V as the predominant term at input to the correlator. This is correlated with the K_2E_V signal at the other input to produce an output dependent on K_2 as required.

ELEMENTS OF AN ADAPTIVE SYSTEM

Complex Attenuator

A diagram of a complex attenuator is shown in Fig. 4. The signal input is fed to a 90° hybrid and each output passed through an attenuator network before recombination. To provide amplitude ratios in the range 0–1 and in any phase between 0° and 360° it is necessary for the attenuator networks to cause phase reversal. This is accomplished by utilising the phase shifting properties of 90° hybrids and the reflecting properties of the PIN diode loads. The attenuation and phase are controlled by biasing PIN diodes mounted on the arms of the hybrids. Since each quadrature component can be independently controlled, the output, on recombination, will have the desired all-phase characteristics.

Pilot-tone Receiver

For pilot-tone reception a narrow-band tuned receiver is needed. CCIR restrictions on the maximum level of CW signals from satellites exist to prevent interference, so low-level tones must be used. Hence, pilot-tone receivers must be narrow-band to increase sensitivity. As a consequence, phase-locked loop detection systems must be used. It is convenient to use

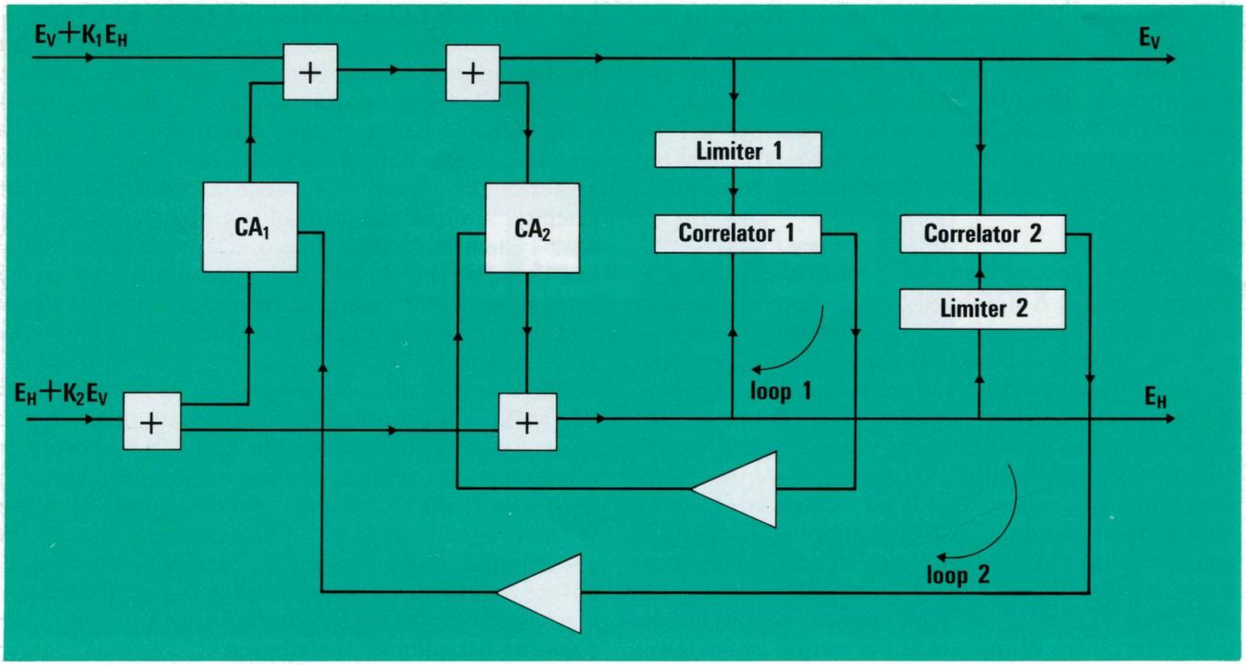


Fig. 3. An adaptive cancellation system using correlators.

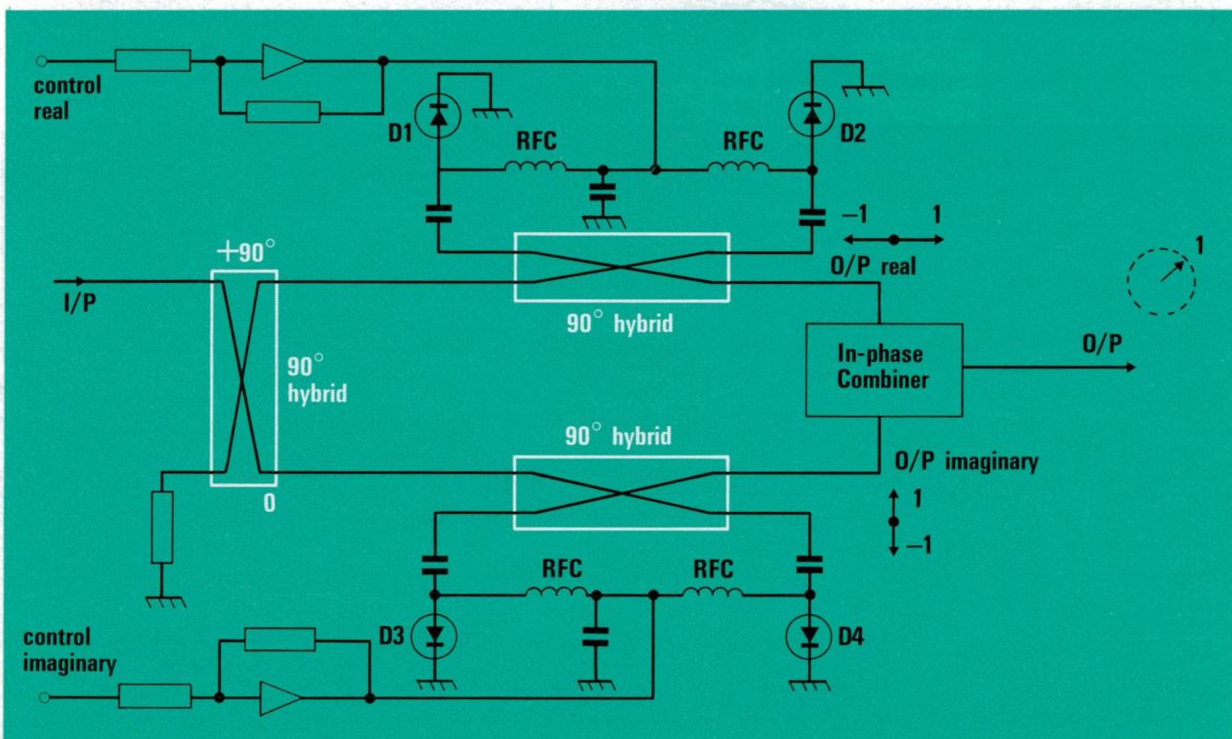


Fig. 4. A complex attenuator.

the main or co-polar component of the pilot tone as a reference for the phase-lock loop. The much lower level cross-polar component can then be detected in a synchronous detector. If the cross-polar output is required in two quadrature components, (to drive a complex attenuator, for example) two synchronous detectors with quadrature references will be needed.

Correlators

The general arrangement of a simple correlator is shown in Fig. 5. A simplified explanation of operation can be given by considering the cross-polar coupling factor K_1 to be composed of an amplitude component C_1 and a phase ϕ. As described earlier, the inputs to the correlators, after limiting, will comprise two signals; one, $\cos \omega t$, without the cross-coupling factor, and the other, $C_1 \cos(\omega t + \phi)$. Hence, the upper mixer (see Fig. 5) will have $\sin \omega t + C_1 \cos(\omega t + \phi)$ appearing at its inputs and the multiplied output will contain sum and difference signals. The sum frequency 2ω is removed by the filter leaving the difference $C_1 \sin \phi$ at the output. Similarly the difference $C_1 \cos \phi$ appears at the output of the lower mixer. These two components are the real and imaginary parts of the cross-polar coupling. An analysis of cancellation loops using correlators is given by Brandwood[1].

EXPERIMENTAL CANCELLATION SYSTEM

A satellite receiving station with a 3 m diameter dish has been constructed at Crawley Court, Winchester, Hampshire, for propagation and TV measurements with OTS. The opportunity was taken to install an adaptive cancellation system and measure the performance using TV transmissions from the satellite. A block diagram of the experimental pilot-tone system is given in Fig. 6. The interfering signal and co-polar component of the pilot tone are received by the lower receiving channel and the wanted signal and cross-polar component of the pilot tone in the upper channel.

The complex attenuator operates at the first IF of 750 MHz. The cancellation possible with this system is determined by the attenuation limits of the complex attenuator. The minimum attenuation of the network used was 11 dB and the maximum was 40 dB over a bandwidth of 100 MHz. Cable lengths up to the cancellation point had to be carefully matched to ensure that the total delay between the aerial feed and cancellation point were the same in each channel, thus ensuring broadband cancellation.

The co-polar and cross-polar component of the pilot tone are further down-converted to 70 MHz and fed to the pilot-tone receiver which uses a phase-lock loop and quadrature synchronous detectors, as

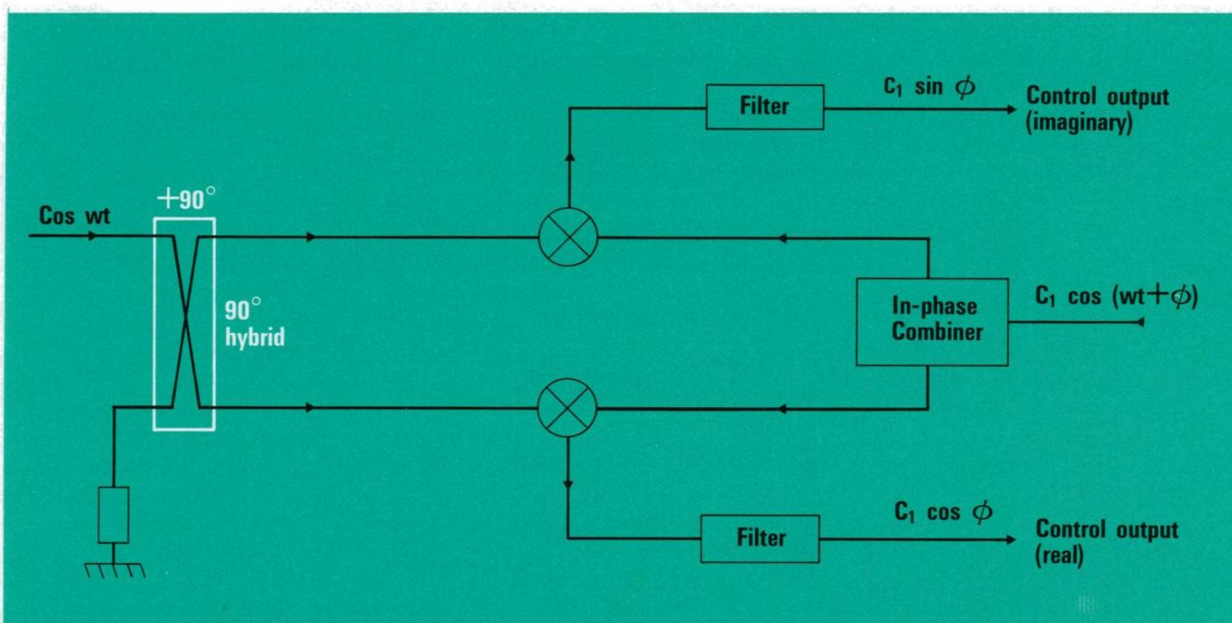


Fig. 5. A simple correlator.

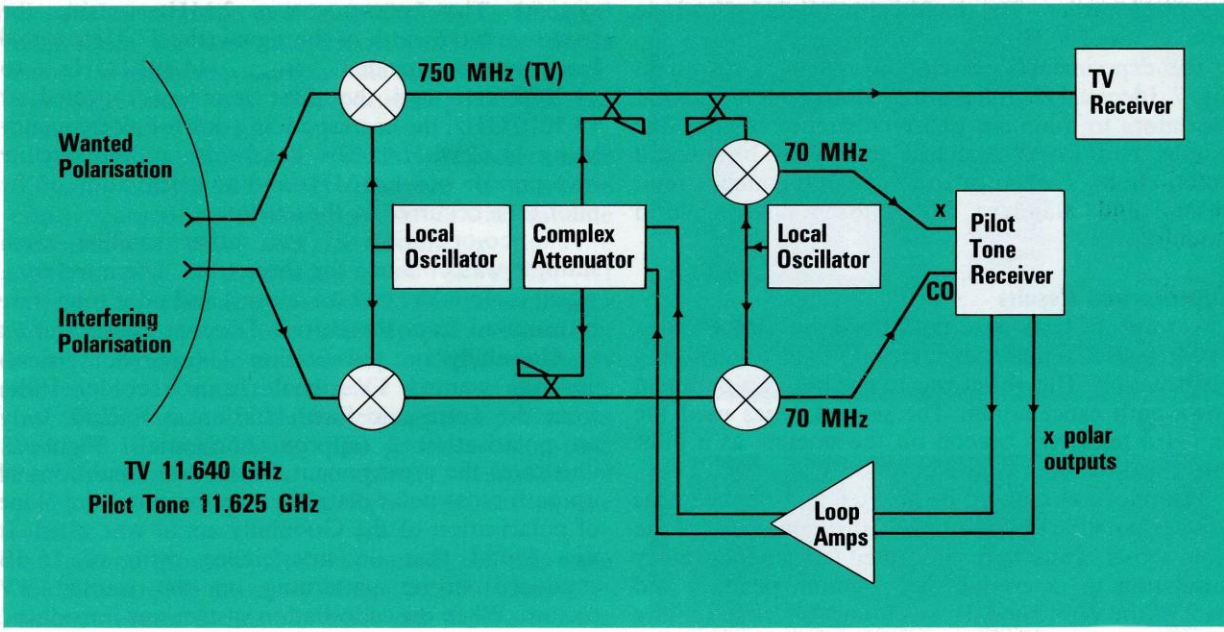


Fig. 6. An experimental pilot-tone system.

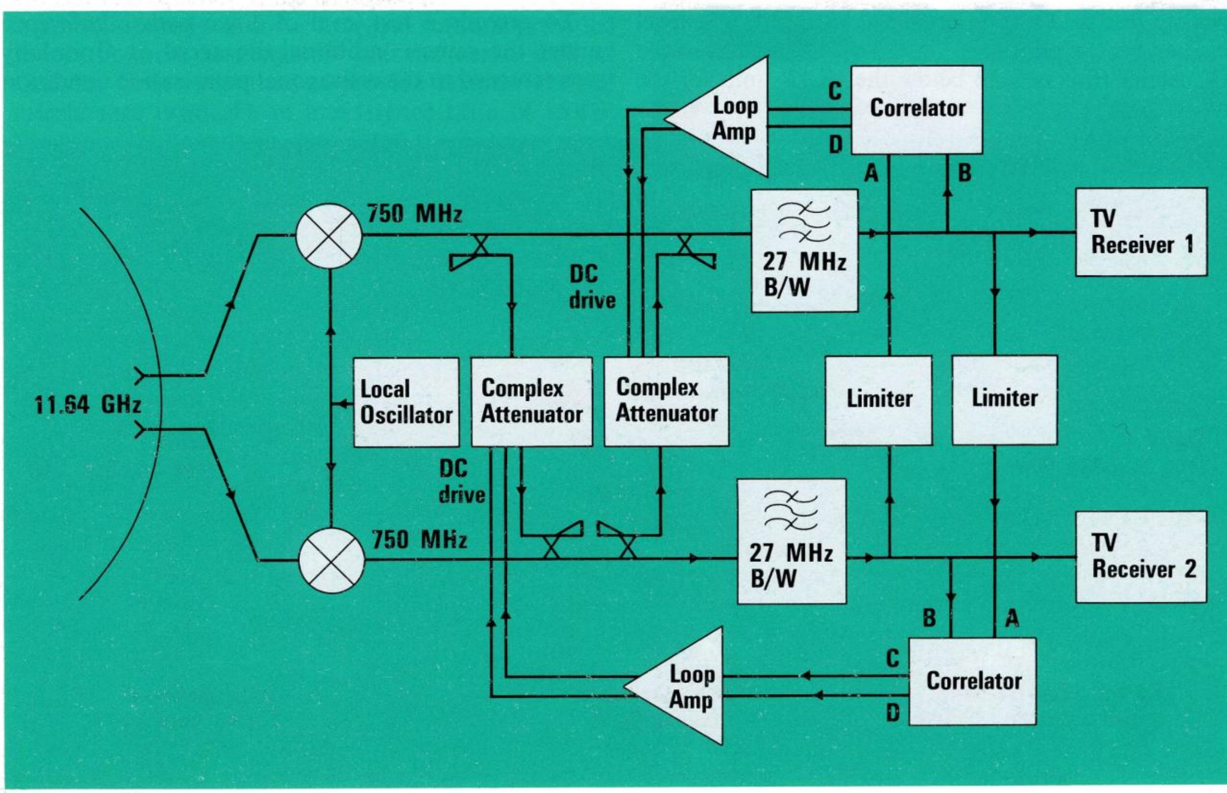


Fig. 7. An experimental correlation system.

described earlier. The bandwidth of the pilot-tone receiver was 200 Hz.

The experimental correlation system is shown in Fig. 7. Identical channels are used with common local oscillators to maintain phase coherence. Again, line lengths had to be matched to obtain broadband cancellation. The correlators use integrated circuit mixers and standard 90° and in-phase hybrid modules.

Experimental Results

Two series of tests were performed with pilot tones. The first used pilot tones inserted at the transmitting earth station. The object was to test both up-path and down-path cancellation. The second series used the onboard telemetry beacon on the satellite as a pilot tone for down-link cancellation only.

The pilot tone should be inserted at a frequency as close as possible to, but outside, the bandwidth of the main signal. Tests were performed using a laboratory simulation to determine the optimum position and level of the pilot tone. It was found that the limiting factor was not visible patterning on the TV signal due to interference, but failure of the pilot-tone receiver to lock-up due to TV interference at its input. The level selected for the pilot tone was 15 dB below that of the TV carrier (this is 7 dB below the CCIR limit for the system). The frequency was 2 MHz outside the spectrum bandwidth of the signal (the 27 MHz signal bandwidth extended from 14.3012 GHz to 14.3039 GHz and the pilot tone was injected at 14.3010 GHz, the corresponding down-link frequency being 11.625 GHz). The bandwidth of the satellite transponder was 120 MHz and no attenuation of the pilot tone occurred in the satellite.

The co-operation of two other satellite earth stations was obtained for these tests. The interfering signal (colour bar test waveform) and pilot tone were transmitted from the British Telecom Earth Station at Goonhilly on polarisation 1 (approx. vertical) and the wanted TV signal (from a colour slide) from the Telespazio Earth Station at Fucino, Italy on polarisation 2 (approx. horizontal). Figure 8 illustrates the arrangement. When test conditions of up-path cross-polar coupling were required the plane of polarisation of the Goonhilly aerial was tilted. It was found that an interference ratio of 15 dB produced strong patterning on the wanted TV picture. When the cancellation system was introduced the patterning was significantly reduced, but not eliminated completely.

To provide a test level of down-path interference under the same conditions, the aerial at Goonhilly was returned to the orthogonal polarisation condition

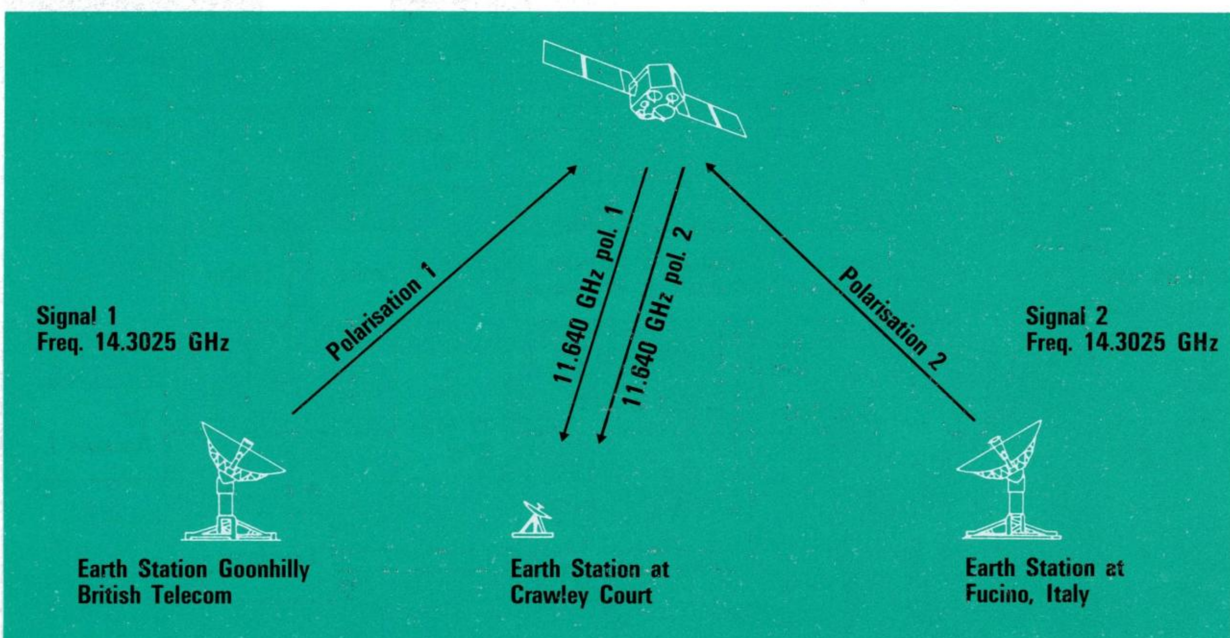


Fig. 8. The arrangements for an experiment with OTS.

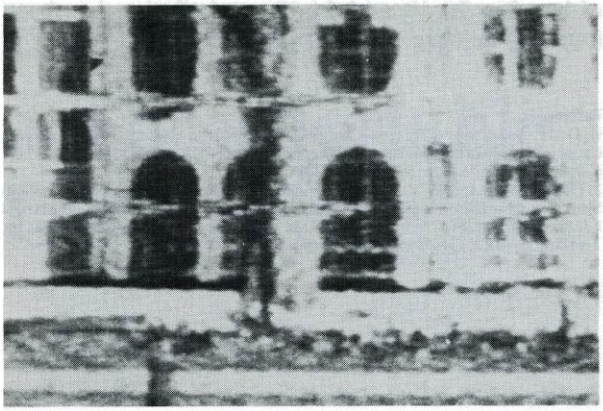
and the aerial at the receiver at Crawley Court tilted to produce the same interference ratio of 15 dB, as before. With these conditions, the cancellation system was introduced and the patterning disappeared completely.

The residual interference which was present after up-path cancellation was attempted is therefore clearly caused by intermodulation in the satellite transponder. This intermodulation is therefore significant at interference ratios of 15 dB. At interference ratios no worse than 25 dB, patterning on TV pictures is not visible. Hence up-path cancellation is only fully effective at moderate to slight conditions of depolarisation, at interference ratios of between, say, 20 dB and 24 dB. Nevertheless, the improvement at 15 dB is worth having. The problem of up-path depolarisation could be completely overcome, of course, by having a cancellation system in the satellite.

A second group of tests was carried out using the onboard satellite telemetry beacon as pilot tone. This beacon, which is linearly polarised, operates at a frequency of 11.575 GHz which is relatively close to the centre frequency of the transponder (11.640 GHz). Again, Goonhilly and Fucino earth stations provided the orthogonal test signals and the aerial feed at Crawley Court was tilted to provide various levels of interference ratio. At an interference ratio of 15 dB, the cancellation system eliminated the patterning on the picture as before. At 6 dB, the system reduced the patterning to a just discernible level (Fig. 9).

The closed loop response time of the system to a stepped change was 600 ms. This is expected to be adequate to cope with atmospheric changes in depolarisation, which are relatively slow phenomena.

The correlation system was also tested using two orthogonal TV signals from the satellite. Again, the feed of the Crawley Court aerial was tilted to simulate various levels of cross-polar interference. Results showed that the system was successful in reducing the effect of interference significantly (by about one picture grade at interference ratios of about 10 dB). Complete elimination of the interference was not obtained due to imperfections in the action of the very simple correlators used. Each correlator has to deal with two TV signals and for perfect performance must respond to one of these only. The mixer type correlators used do not remove completely the effects of the second TV signal and a small d.c. offset results, thus interfering with the locking point of the loop. Further work on correlator design is required to improve this.



▲ uncancelled ▼ cancelled

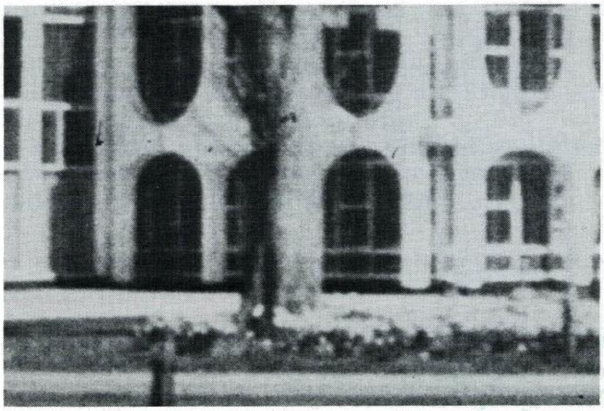


Fig. 9. Examples of received TV pictures before and after an adaptive cancellation system was applied to the down-link.

Comparing the two methods of error detection, the pilot-tone method was the more efficient but it was inconvenient. The correlator method is very simple but, with the equipment used, was somewhat less efficient.

CONCLUSIONS

An adaptive cross-polar cancellation system has been developed for use with satellite transmissions using orthogonal polarisation. The system has proved very effective in cancelling interference arising from down-path cross-polarisation.

In the case of up-path cross-polarisation in conditions of severe interference (i.e. interference ratios of 15 dB and worse) the efficiency of cancellation was limited by intermodulation in the satellite transponder. However, in conditions of slight-to-moderate levels of interference (i.e. interference ratios

of between 20 dB and 24 dB) cancellation has been found to be fully effective.

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Experience with a Transportable Up-link

by B. F. Salkeld

Synopsis
Since 1978 the IBA has been experimenting with a transportable satellite earth station designed to transmit television signals via the OTS satellite and using the 14 GHz up-link frequency band. The object of these experiments has been to develop the use of transportable satellite up-links for reporting news and events by satellite on a national and international scale. This chapter describes the background to the requirement for such terminals and reports on the technical results obtained.

The practical experience gained has made it possible to define the desirable features of operational terminals of this type, and these are considered in detail.

Television Outside Broadcasts (TVOBs) have made use of temporary microwave links for over 25 years to relay signals from external sites to a studio centre. Much advanced planning work is involved in arranging these temporary microwave links, particularly when long distances are involved and many hops are used.

When there is very limited advance notice of a temporary link being required, e.g. unforeseen news events, it is sometimes found impossible to set up the temporary link in the time available to get the signals back to the permanent network. The alternatives of recording the event on film or videotape may also mean that there can be delays in providing vision coverage. Even where repeated use is made of a particular location, such as a sports arena, it is not always economic to have sufficient permanent links available to meet the requirements of major national or international events. On such occasions additional temporary links are usually set up to meet the peak demand.

A small satellite up-link terminal could establish such temporary connections easily, independent of distance.[1] The experimental Orbital Test Satellite (OTS) was designed to evaluate communications techniques and propagation in the 11/14 GHz band. It had been assumed that use would be made of only fixed ground stations, which tend to have large dish aerials (typically 10–19 metres diameter).

The IBA decided to extend its studies with OTS by building a transportable up-link terminal to carry out experiments to determine the feasibility of satellite techniques for outside broadcasts and news coverage. The required size of the up-link dish aerial depends on the power of the earth station transmitter and also on the sensitivity of the satellite receiving system. Although the receivers used on the OTS channels are not particularly suited in this latter respect, initial calculations showed that it would be possible to design a terminal of acceptable physical proportions.

This chapter describes the IBA equipment and the experience gained. The features that are recommended should be of value in designing operational up-links to be used in the future by broadcast organisations.

THE EQUIPMENT

The IBA experimental up-link terminal, the first of its kind in Europe, was constructed in 1978. The terminal consists of a small cabin to house the

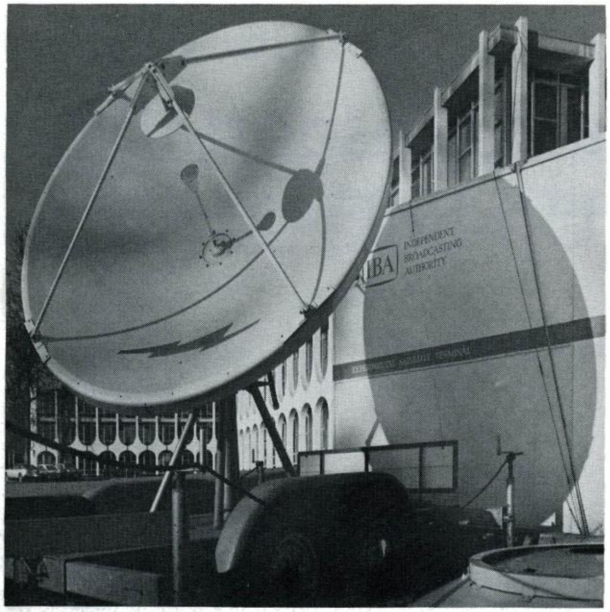


Fig. 1. The IBA transportable up-link.

transmitting equipment, together with a separate 2.5 metre diameter dish aerial mounted on a trailer (Fig. 1) The complete assembly is easily transported by a single vehicle which carries the equipment cabin and tows the trailer-mounted aerial.

The equipment cabin is 2.5 metres high, and measures approximately 3 m by 2.25 m. Inside is a standard earth station high power amplifier which gives an r.f. output of $1\frac{1}{2}$ kW. A single equipment rack contains the modulator, up-converter and auxiliary equipment. A simplified block diagram of the complete system is shown in Fig. 2.

The terminal equipment includes a simple receiver to pick up beacon signals transmitted by the satellite; this makes it possible to align the dish aerial prior to transmission. The beacon signals are displayed on a spectrum analyser; to make it easier to find these beacon signals on the analyser, the receiver includes its own marker signals, close in frequency (and at a similar level) to those transmitted by the satellite.

The Aerial

The aerial chosen was a paraboloid reflector of 2.4 m diameter (a convenient size for road transport) fitted with a Cassegrain feed and sub-reflector providing a gain of 48.5 dB at 14.3 GHz. To set the aerial elevation initially, an inclinometer is attached to the aerial reflector. A compass bearing is taken across the front face of the dish for azimuth adjustment. The spectrum analyser connected to the output of the beacon receiver is then placed on the trailer platform within view of the operator. The aerial is panned, first in azimuth, then in elevation. A

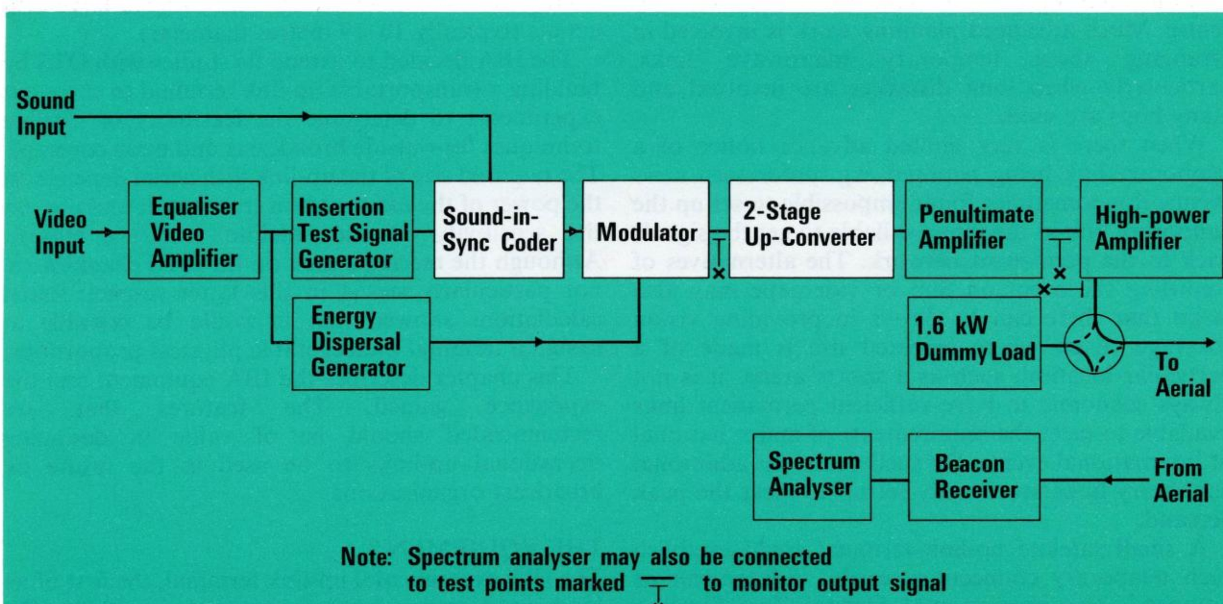


Fig. 2. A block diagram of the up-link equipment.

small azimuthal adjustment is normally sufficient to bring the satellite beacon signal within view on the analyser.

RESULTS

Experimental transmissions were carried out using both 625 and 525-line television signals. The sound channel used sound-in-sync or alternatively an FM sub-carrier at either 6 MHz or 7.5 MHz. Transmissions were made from a variety of locations, including city centre sites, open country, and from an off-shore oil platform in the North Sea. It was considered that assessment of the practical problems of using the up-link in an operational environment would be of equal importance to actual performance measurements.

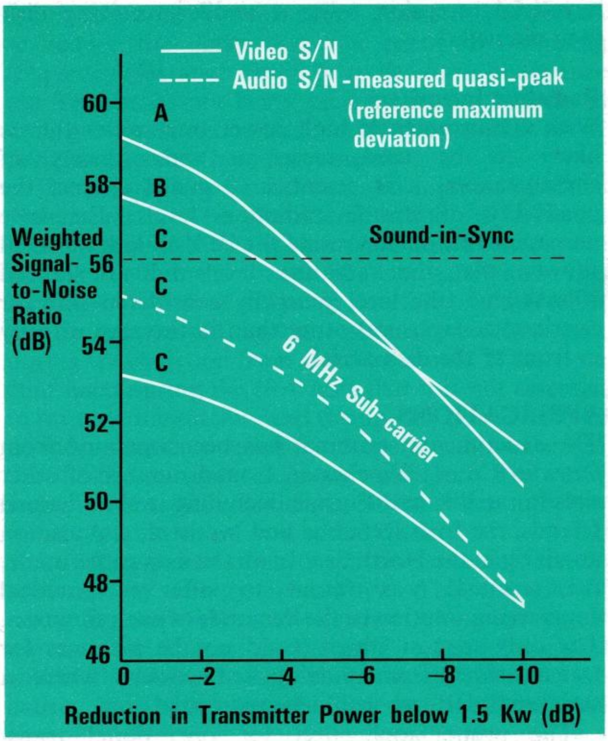
Continuous measurements were taken during some periods of transmissions; no significant variation in performance was observed, other than a slight change in noise level with varying propagation conditions. A deliberate reduction in up-link transmit power affected only the signal-to-noise performance up to the point when threshold was reached.

The overall performance was found to meet the CCIR requirements for long-distance terrestrial or satellite transmission links (CCIR Recommendation 567). Results were comparable to those of a typical permanent single inter-city link, even though the overall geographic span represented many terrestrial links in tandem.

Overall Tests

The performance obtained from the terminal is determined almost entirely by the sensitivities of the ground receiving system and of the satellite itself. Figure 3 shows the measured noise performance with various configurations of satellite and ground receiving station.

In order to obtain optimum noise performance, the satellite transponder gain was normally set to maximum when testing the up-link. The effect of this is to minimise the transmitter power required by the up-link. This is an important consideration, since the power radiated by a mobile up-link terminal should be kept as low as possible in order to reduce the possibility of interference to other satellites. With the up-link used in the UK in conjunction with OTS, an up-link transmitter power of as little as 150 W, corresponding to an effective radiated power (e.r.p.) of approximately 70 dBW, gave very acceptable picture quality when the signal was received on a large earth station (receiving aerial 19 m diameter). This



SATELLITE TRANSMIT AERIAL		EARTH RECEIVE AERIAL	OTS CHANNEL
A = Eurobeam	+	19 m diameter	2
B = Spotbeam	+	19 m diameter	4
C = Spotbeam	+	3 m diameter	4

Fig. 3. Measured noise performance.

confirms that use of the full 1.5 kW output power of the up-link would enable operation from the extreme edge of the OTS Eurobeam coverage area. Table 1 shows the vision performance obtained with

TABLE 1: VISION PERFORMANCE OF THE MOBILE UP-LINK OPERATING VIA OTS CHANNEL 4 INTO 3-METRE DIAMETER RECEIVE TERMINAL

VIDEO PARAMETER	IMPAIRMENT
Luminance non-linearity	1.5%
Differential gain	3.2%
Differential phase	1.0%
Chrominance-luminance crosstalk	0.6%
Chrominance-luminance gain inequality	+0.7 dB
Chrominance-luminance delay inequality	+11 ns
2T pulse K rating	1.0%

terrestrial reception using a smaller receiving dish (3 m diameter).

Radiation Intensity

With a transportable high-power transmitter that is likely to be used under a wide variety of circumstances, it is essential to guard against the possibility of unsafe radiation levels. Extensive measurements made around the IBA up-link terminal showed that the radiation level did not exceed 10 mW/cm^2 (the level generally considered safe for continuous exposure) other than in the area directly in front of the dish aerial.

APPLICATIONS

The experimental terminal has been operated from Crawley Court, Winchester, from a number of other sites in the UK and Europe, including in the Channel Islands, the Irish Republic and Madeira, and also on an oil rig in the North Sea. In all the uses so far made, the terminal was found to offer a practical engineering solution to the demands of each situation. The only request which could not be met was for transmissions from moving sea vessels, where a stabilised platform would be required.

The prime application for operational transportable terminals of this type is seen to be in live coverage of news stories. Other uses were found to arise in the following circumstances:

(i) Locations from which no other form of link can be established, for example on distant islands or oil platforms.

(ii) Remote locations where terrestrial links could be set up, but where a satellite up-link would provide a much more straightforward solution e.g. where it would be necessary to set up many terrestrial links in tandem.

(iii) Situatons where links already exist, but are not sufficient to cope with occasional peaks in demand. Major international news or sporting events are examples of this.

(iv) 'Invisible Traffic'. It was noted on several occasions that the availability of a high-quality satellite link encouraged unforeseen additional uses. This appears to be an example of a well-known phenomenon that the existence of a communication channel creates a demand for its use.

OPERATIONAL CONSIDERATIONS

The IBA's experiments with the up-link have created a fund of knowledge for designing future operational mobile up-links. The overriding need is for a terminal which is able to reach a site easily and which provides good communications to base. The following detailed points should be considered in any new design.

Transportation

The height of the experimental terminal was found to be a limitation for air transport. Considerable scope exists to reduce the size; standard aircraft 'igloo' containers are available which could form a convenient basis for a mobile design. For use nearer to base a single self-contained vehicle is practical.

Radiated Power

The experimental terminal can produce sufficient r.f. power (an e.r.p. of approximately 80 dBW) to operate from the extreme edge of the OTS Eurobeam coverage area. Significant savings in size and weight appear to be possible with a small reduction in r.f. output power (and consequently a reduction in the coverage zone). For operation within central Europe, a power level of a few hundred watts would be adequate. This would allow a single-phase mains generator to be used which could be self-contained, although the requirement for a three-phase power supply for the experimental up-link terminal was not found to be a limitation at the sites where it was used.

Communications

Good communications with the mobile terminal are essential. A public telephone connection was used for all the experimental work described. Contact is necessary with the receiving ground station, with the studio centre and with the satellite control centre. Two-way speech channels via the satellite appear to be the best way to achieve this—especially if the reception terminal were to be sited at the studio.

Input Conditions

Mains hum and interference on the temporary video cables feeding the up-link from electronic cameras or videotape recorders used on location can sometimes seriously affect the quality of the transmitted pictures. Visible 'hum-bars' on the picture can be caused by differences of earth potential between the camera equipment or VTRs on location and the up-link equipment. The effects may be visible only at reception points many miles distant. This was a frequent difficulty during the experimental phase. It was awkward to deal with systematically and wasteful of time on site.

One solution would be to use a simple optical fibre

connection between the local picture sources and the up-link; such a non-metallic transmission cable would isolate any difference of earth potentials.

Reliability

Despite the hazards of transportation and long periods of standing idle in the open without heating or ventilation, the reliability of the equipment was found to be excellent. Vibration in transit led initially to repeated fractures of high-tension leads in the power amplifier. These leads were replaced with an alternative design which has proved very reliable.

The few faults encountered were all the result of mechanical stress rather than of electrical failure. Only elementary anti-vibration mounts were used, and further attention to this feature would appear to be worthwhile in operational units.

Reverse Vision

It would be of advantage to incorporate a simple receiver to display the satellite output signal in the up-link terminal. This facility could be incorporated at modest additional cost and would allow for an elementary check of transmission quality. It would also help remove any ambiguity about the nature of any impairments reported from the studio centre. It could be used to check that the satellite transmission path is available and also to determine whether satellite transponder saturation is taking place (Note: at this point an increase in up-link power would provide no further improvement in signal quality transmitted by the satellite, and would risk overheating the transponder output stages).

Multiple Sound Channels

For international transmission it may be necessary to provide more than a single sound channel. Two channels (one obtained by the use of sound-in-sync and the second on an FM sub-carrier) may often be sufficient. Should a greater number of channels be required, this could be achieved with a digitally modulated sub-carrier.

Frequency Clearance

The 1979 Geneva World Broadcasting Satellite Administration Conference (WARC '79) amended the international frequency table to permit land-mobile to satellite systems in the 14–14.5 GHz frequency band, but sharing on a secondary basis with the primary space and terrestrial services. The way in which this sharing will be administered in the UK is still under consideration. A possible approach to reduce the delay that can occur in obtaining frequency clearance would be to detemine in advance the frequencies not being used by terrestrial links in each geographic zone and for mobile up-links to be permitted to use these frequencies.

The possibility of interference to adjacent satellites also needs to be considered. Use of a small transmitting dish means that the r.f. power from the up-link equipment must be increased and this increases the risk of off-beam interference; this effect can be mimimised by increasing the satellite gain during transmission from small terminals. It has been confirmed during the IBA tests that it is not essential to saturate the satellite and the up-link power need be no more than that necessary to operate above the FM threshold at the receiving station. The FM improvement effect of wide deviation is then sufficient for acceptable vision and sound quality.

A further reduction in the interference risk can be achieved by energy spreading.[2] The amount of triangular dispersal signal which can be employed is normally determined by the need to keep the signal within the defined channel bandwidth. Should an entire wide-band transponder be available and economic to use, it would be possible to employ a larger dispersal signal than may normally be possible.

If the preceding measures prove insufficient to avoid interference within a closely-packed satellite orbit, the introduction of digital modulation could be the most effective solution. This would allow the frequency spectrum of the transmitted signal to be much more evenly distributed across the channel bandwidth than is possible for an FM transmission.

SUMMARY

The results of experimental transmissions from a small satellite up-link have proved encouraging. The practical experience gained has been valuable in leading the way towards possible future up-link designs.

The main features of the trials may be summarised:

(i) In conjunction with OTS, the performance obtained met the CCIR specification and design objectives for a hypothetical reference satellite circuit (Recommendation 567). This was achieved with reception both on a major earth station (19-metre diameter dish aerial) and on a smaller ground station with a 3 m receiving dish.

(ii) Transportation by either road or sea was found to be straightforward.

(iii) Terminal alignment proved to be straightforward and stable. Operational transmissions could be started within an hour of arrival on site. Reliable operation was then possible for several days at a time without further adjustments.

(iv) Equally good results were obtained at a variety of locations, including city centres, open country, and an oil platform at sea.

(v) Good performance was obtained with both 625-line and 525-line television signals, whether using sound-in-syncs or sub-carrier sound channels.

(vi) The experience gained shows that a significant reduction in size of the up-link terminal is possible. This means that compact low-power mobile terminals could be used for day-to-day OB and news operations.

(vii) With the limited number of satellites sharing the same orbit and frequency band, the risks of interference to adjacent satellites are at present manageable.

CONCLUSION

The World Administrative Radio Conference (WARC '79) introduced a modification to the international frequency table to permit land-mobile satellite systems in the 14–14.5 GHz up-link frequency band. IBA experience shows that transportable television up-links provide a valuable alternative way of meeting television news and OB link requirements. They could be put to operational use with the European Communication Satellite (ECS), due to be launched in 1982.

ACKNOWLEDGEMENT

The experimental transmissions to OTS described in this chapter were conducted with the permission of British Telecom. The assistance of BT staff in carrying out several of the tests is gratefully acknowledged.

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Weiterentwicklungen und Möglichkeiten von Satelliten

Übersicht

Die mit dem Raumpendler und der Trägerrakete Ariane erzielten Erfolge haben sowohl die USA als auch die europäischen Länder in die Lage versetzt, größere und leistungsstärkere Satelliten in geostationäre Umlaufbahnen zu bringen. Die neueren Arbeiten der IBA auf dem Gebiet der Nachrichtenübertragung unter Einsatz von Satelliten werden kurz zusammengefaßt. Es bestehen heute gute Gründe für die Inbetrachtziehung neuer Moduliersysteme für die unmittelbare Satellitensendung. Als europäische Norm wird ein Multiplex-Analogsignalsystem umrissen.

Es wird ein Gesamtüberblick über das gesamte Rundfunkwesen gebracht, da dadurch sowohl die Anforderungen an, als auch die Konstruktion von Satelliten beeinflußt werden.

Normen für den Fernmeldesatelliten-Funkdienst

Übersicht

Die direkte Fernsehsendung, die unmittelbar vom Satelliten ausgestrahlt wird, dürfte Mitte der Achtziger-Jahre in Europa zur Realität werden. Die Pläne für eine solchen Fernsehdienst wurden 1977 von der WARC definiert, basieren jedoch zur Zeit auf der Übertragung konventioneller PAL/SECAM-Signale, die keine Möglichkeit für einen zufriedenstellenden Empfang außerhalb nationaler Grenzen bieten. Glücklicherweise erlauben die WARC-Pläne auch andere Moduliersysteme im Rahmen bestimmter Grundregeln. Die IBA schlägt aus diesem Grunde ein 'Multiplex-Analogkomponenten-Signal' (MAC) vor, das als Basis für eine einheitliche europäische Norm für das Satellitenfernsehen angewandt werden könnte. Ein solches System mit getrennten Signalkomponenten könnte außerdem in absehbarer Zeit zur Erzielung von Signalen von Spitzenqualität für die Projektion auf große Schirme und Anzeigen mit hoher Auflösung verwendet werden.

Ein Digital-Videosignalverschlüssler für 60 Mbit/s

Übersicht

Verfahren für die Digitalverschlüsselung von Fernsehsignalen werden seit mehreren Jahren von der IBA untersucht. Die besonderen Anforderungen an die Bitgeschwindigkeit und die Fehlerquotengrenzen bei einem Satelliten-Antwortsender stellten unter Berücksichtigung der gegenwärtigen Fachkenntnisse und der früher gesammelten Erfahrungen eine echte Herausforderung dar. Aus diesem Grunde wurde ein Videosignal-Verschlüssler spezifisch zur Verwendung bei Satellitenübertragungen konstruiert und entwickelt, der selbst bei Schwundbedingungen noch eine Bildqualität liefert, die für die Übertragung ausreicht. Der Prototyp wurde zunächst durch Simulation der Eigenschaften eines Satellitenkanals überprüft. Später im Jahre 1980 bewährte sich dann das Gerät auch bei Versuchsübertragungen unter Anwendung des OTS-Satelliten.

Die Satellitenübertragung von Digital-fernsehsignalen bei 60 Mbit/s

Übersicht

In dieser Abfassung wird über eine Reihe von Versuchssendungen berichtet. Es handelt sich um die Sendung von digital verschlüsselten PAL System I Fernsehsignalen bei 60 Mbit/s unter Einsatz des OTS-Satelliten.

Es werden verschiedene Gesichtspunkte des werwendeten und der Satelliten-QPSK-Modulations-systems Übertragungskanal betrachtet und die Ergebnisse berichtet.

Des weiteren wird über die subjektiven Prüfungen berichtet und ein Vergleich zwischen Digital- und Analog-FM-Übertragung von Fernsehsignalen über Satelliten angestellt.

Ein Empfängersystem mit Selbstanpassender Aufhebung zur Reduktion von Kreuz-Polarisierten Störungen bei Satelliten-Sendern mit Doppelpolarisierung

Übersicht

Die Kapazität von Satellitenübertragungsanlagen läßt sich durch mehrfache Frequenznutzung erweitern. Bei einem solcher Verfahren kommt doppelt rechtwinklige Polarisierung zur Anwendung. Bei den in modernen Systemen benutzten Frequenzen vermindert sich jedoch die Qualität der Polarisierung bei atmosphärischem Niederschlag. In dieser Abfassung wird ein verbessertes, selbstanpassendes System für die Aufhebung solcher Kreuzpolarisierungen beschrieben, das die Kanaltrennung aufrechterhält. Vom Satellitensignal abgeleitete Steuerspannungen werden zur Steuerung einer Kreuzkopplungs schaltung zwischen den Kanälen im Empfänger herangezogen, so daß das unerwünschte, kreuzpolarisierte Signal im gewünschten Kanal aufgehoben wird. Dieses System wurde versuchsweise bei Fernsehübertragungen des OTS-Testsatelliten mit erfolgreicher Störungsaufhebung eingesetzt.

Ausbreitungsuntersuchungen

Übersicht

Dieser Artikel beschreibt die Ergebnisse der Ausbreitungsversuche, die während der ersten beiden Betriebsjahre des OTS-Satelliten von Crawley Court durchgeführt wurden.

Bei den Versuchen kamen im Satelliten angeordnete Leitstrahlsender mit konstanter Sendeleistung zum Einsatz. Die Änderungen in der Stärke der eingehenden Signale wurden zur Ermittlung der atmosphärischen Signalabschwächung und Depolarisierung herangezogen. Es wurden Ergebnisse sowohl für Kreis- als auch Linearpolarisierung erhalten.

Erfahrungen mit einer Transportablen Erdsendestation

Übersicht

Seit 1978 experimentiert die IBA mit einer transportablen Erdsenderstation für den Nachrichtenverkehr mit Satelliten, der für die Übertragung von Fernsehsignalen über den OTS-Satelliten verwendet wird und das 14 GHz-Frequenzband für Sendungen verwendet. Ziel dieser Experimente ist die Entwicklung eines transportablen Senders für die Sendung an Satelliten im Rahmen der Nachrichtenübermittlung bzw. Außenübertragung über Satelliten auf nationaler und internationaler Ebene. In diesem Artikel wird der Hintergrund der Anforderungen an solche Sender beschrieben sowie über die erzielten Ergebnisse berichtet.

Die gesammelten praktischen Erfahrungen erlaubten eine Definition der wünschenswerten Merkmale von Sendestationen dieser Type, und diese werden eingehend erörtert.

Dieser Artikel enthält eine kurze Beschreibung der Hauptziele der Versuche, der durchgeführten Übertragungen und der erzielten Ergebnisse. Die Ergebnisse bestätigen die praktische Möglichkeit der Einführung nationaler Fernsehsendungen über Satelliten in Europa auf der Basis der auf der World Administrative Radio Conference im Jahre 1977 verabschiedeten Pläne.

Übersetzungen

Analog-Fernsehübertragungsversuche mit dem OTS-Satelliten

Übersicht

Im Mai 1978 wurde der erste europäische Nachrichtensatellit OTS erfolgreich in eine Umlaufbahn gebracht. Bei dem OTS-Satelliten handelt es sich um einen Versuchssatelliten, der die Frequenzbänder von 11 GHz und 14 GHz nutzt. Der Senderteil des Satelliten arbeitet bei 11 GHz und liegt damit dicht in der Nähe des Bereichs von 11,7 bis 12,5 GHz, der für die Abstrahlung von Sendungen direkt von Nachrichtensatelliten aus geplant ist. Damit eignet sich dieser Satellit ganz besonders für Versuche, die sich auf Direktsendungen beziehen.

Ein Programm von Direktsendeversuchen, das von der EBU koordiniert wurde, begann im Juni 1979. Dabei kamen Erdsendestationen in England, Frankreich, Deutschland und Italien zum Einsatz, sowie eine Vielzahl von Kleinempfängerstationen überall in Europa. Die IBA nahm an diesen Versuchen teil. Dabei kam die 3 m-Empfängerstation des Engineering Headquarters in Crawley Court in der Nähe von Winchester zum Einsatz.

Développements et Perspectives des Satellites

Résumé

La réussite de la navette spatiale et du lanceur Ariane a fourni aux Etats-Unis et à l'Europe la capacité de mettre des satellites de télécommunication plus grands et plus puissants en orbite géostationnaire. On a résumé le travail d'IBA sur les communications par satellite. Il y a beaucoup à dire pour l'étude de nouveaux systèmes de modulation pour le Service de Télécommunication par Satellite. On souligne, comme Standard Européen, un Système de Signal Analogue par Multiplexage.

On a pris en considération l'ensemble des télécommunications étant donné que ceci peut avoir des conséquences sur les caractéristiques et la forme des satellites.

Normes pour les Communications à Satellite

Résumé

Les Télécommunications directes par Satellite deviendront une réalité en Europe d'ici le milieu des années 1980. Les plans pour le service ont été définis par le WARC de 1977 mais, à l'heure actuelle, ils sont fondés sur des signaux PAL/SECAM traditionnels qui ne permettent pas une réception satisfaisante à travers les frontières nationales. Heureusement les plans WARC permettent l'utilisation d'autres systèmes de modulation, définis par certaines règles. Par conséquent, IBA propose un signal à 'Composante Analogue de Multiplexage' (Multiplexed Analogue Component: MAC) qui pourrait servir de base pour un Standard Européen unique pour les Télécommunications directes par Satellite. Un tel système, qui comporterait des signaux à composantes séparées, pourrait éventuellement fournir des signaux de qualité élevée pour une visualisation sur grand-écran et de définition élevée.

Essais de Télévision Analogique Utilisant le Satellite Orbital d'Essai (OTS).

Résumé

En mai 1978 le premier satellite orbital d'essai Européen de télécommunications a été lancé avec succès. Le OTS est un satellite expérimental utilisant les bandes de fréquences 11 GHz et 14 GHz. La liaison inférieure du satellite de 11 GHz est proche de la bande 11.,7 à 12,5 GHz prévue pour la radiodiffusion par satellite. Ceci le rend extrèmement intéressant pour des essais concernant la radiodiffusion en direct.

Un programme d'essais de radiodiffusion en direct, coordonné par l'Union Européen de Radiodiffusion, a commencé en juin 1979. Il comprenait des stations de liaisons vers le satellite en Angleterre, en France, en Allemagne et en Italie, ainsi que de nombreux terminaux de réception dans toute l'Europe. L'Independent Broadcasting Authority prit part a ces essais en utilisant son terminal de réception de 3 mètres de diamètre situé a ses Engineering Headquarters, Crawley Court, près de Winchester.

Expérience avec une Liaison Mobile vers le Satellite

Résumé

Depuis 1978, l'Independent Broadcasting Authority a fait des expériences avec une station terrestre mobile pour satellite conçue pour émettre des signaux de télévision par l'intermédiaire du satellite orbital d'essai utilisant la bande de fréquence de 14 GHz comme liaison vers le satellite. L'objet de ces expériences était de mettre au point l'utilisation de stations de liaison mobiles vers le satellite afin de rendre compte des nouvelles et des événements au moyen du satellite à une échelle nationale et internationale. Cet article décrit l'arrière plan des besoins pour de tels terminaux et rend compte des résultats techniques obtenus.

L'expérience ainsi gagnée à permis de définir les caractéristiques souhaitables pour les terminals opérationnels de ce type et ceux-ci sont examinés en détail.

Cet article décrit brièvement les buts principaux des essais, les transmissions faites et certains des résultats obtenus. Ces résultats confirment qu'il est possible d'introduire un service national de télévision par satellite en Europe basé sur le plan adopté à la World Administrative Radio Conference en 1977.

Essais de Propagation

Résumé

Cet article présente les résultats des expériences de propagation effectuées à Crawley Court dans les deux premières années de la mise en service du satellite orbital d'essai (OTS).

Les expériences ont comporté l'utilisation d'émetteurs radio-phares sur le satellite et fonctionnant à un niveau constant. Les variations des niveaux des signaux reçus ont été utilisées pour la mesure des atténuations atmosphériques et de dépolarisation. Des résultats ont été obtenus à la fois pour la polarisation circulaire et la polarisation linéaire.

Transmission par Satellite de Signaux Digitaux de Télévision de 60 Mbit/s

Résumé

La communication décrit une série d'essais de transmission de signaux de télévision digitalement codés en système PAL I de 60 Mbit/s en utilisant le satellite orbital d'essai.

Les divers aspects du système de modulation QPSK utilisés et le canal du satellite sont examinés, et les résultats sont présentés.

Les résultats d'essais subjectifs du système sont donnés et une comparaison est faite entre les transmissions de télévision par satellite en modulation de fréquence en digital et en analogique.

Un Codeur Digital Video de 60 Mbits/sec.

Résumé

Des techniques pour le codage digital des signaux de télévision ont été étudiées durant de nombreuses années par l'Independent Broadcasting Authority. Les problèmes spéciaux posés par les restrictions des taux de bits et d'erreurs d'un canal de transpondeur de satellite offraient un défi sérieux aux connaissances et à l'expérience précédemment acquises. Un codeur video a été en conséquence conçu et mis au point spécialement pour utilisation avec un satellite afin de fournir des images de qualité même durant les conditions de fading. Le prototype en résultant a été essayé au début en simulant les caractéristiques d'un canal provenant d'un satellite. Plus tard, en 1980, il a fait ses preuves avec succès en transmissions expérimentales provenant du satellite orbital d'essai (OTS).

Système de Réception Utilisant une Annulation Adaptive pour Réduire les Interférences Cross-polaires dans les Liaisons en Double Polarisation avec Satellites

Résumé

La capacité de liaison avec les satellites peut être augmentée en employant la réutilisation de fréquence. Une telle technique utilise des polarisations doubles orthogonales. Aux fréquences utilisées dans les systèmes modernes, toutefois les précipitations atmosphériques réduisent la pureté de la polarisation. Cette communication décrit un système adaptatif amélioré pour l'annulation de telles cross-polarisations et ainsi conserver l'isolation du canal. Des tensions de commande dérivées des signaux provenant du satellite sont disposées afin d'entraîner un réseau de

cross-couplage entre les canaux dans le récepteur afin d'annuler le signal cross-polaire non désiré apparaissant dans le canal souhaité. Le système a été essayé en utilisant des transmissions de télévision provenant du satellite orbital d'essai et une annulation couronnée de succès a été obtenue.

Desarrollos y Oportunidades de los Satélites

Resumen

El éxito de la aeronave espacial y del lanzador Ariane ha capacitado tanto a Europa como a los Estados Unidos para poner en órbitas geoestacionarias satélites de telecomunicación más grandes y potentes. Se resume el trabajo reciente de IBA sobre comunicaciones por satélite. Hay motivo para considerar nuevos sistemas de modulación para el servicio de radiodifusión por satélite. Se presenta un sistema de señales analógico multiplexado como estándar europeo.

Se considera el escenario completo de la radiodifusión de comunicaciones, pues ello puede afectar los requisitos y diseño del satélite.

Normas para los Servicios de Radiodifusión via Satélite

Resumen

La radioemisión directa de televisión por satélite será una realidad en Europa para la mitad de los años 80. Los planes para el servicio fueron definidos por el WARC de 1977, pero actualmente están basados en señales convencionales PAL/SECAM, que no proporcionan recepción satisfactoria a través de las fronteras. Afortunadamente, los planes del WARC permiten el uso de otros esquemas de modulación dentro de ciertas reglas. IBA propone por tanto una señal 'componente analógica multiplexada' (MAC) que podría utilizarse como base de un estándar europeo único para emisiones directas por satélite. Dicho sistema, incorporando señales componentes separadas, podría suministrar a su debido tiempo señales de alta calidad adecuadas para presentación de pantalla grande y alta definición.

Ensayos de Televisión Analógicos con OTS

Resumen

En mayo de 1978 se puso en órbita el primer satélite de telecomunicaciones europeo OTS. El OTS es un satélite experimental que emplea las bandas de frecuencia de 11 GHz y 14 GHz. El enlace descendente del satélite a 11 GHz está cerca de la banda 11,7 a 12,5 GHz planeada para la radiotransmisión por satélite. Esto hace que el mismo sea especialmente adecuado para experimentos relativos a la radiodifusión directa.

En junio de 1979 comenzó un programa de ensayos de radiotransmisión directa coordinado por la Unión de Radiodifusión europea. El mismo incluyó estaciones de enlace ascendente en Inglaterra, Francia, Alemania e Italia, y muchos terminales receptores pequeños en toda Europa. La IBA tomó parte en estas pruebas empleando su terminal receptor de 3 m de diámetro instalado en su sede central, Crawley Court, cerca de Winchester.

Experiencia con un Enlace Ascendente Transportable

Resumen

Desde 1978 la IBA estado experimentando con una estación terrestre de satélite transportable diseñada para transmitir señales de televisión a través del satélite OTS, empleando la banda de frecuencia de enlace ascendente de 14 GHz. El objeto de estos experimentos ha sido desarrollar el uso de enlaces ascendentes de satélite transportables para transmitir noticias y acontecimientos por satélite a escala nacional e internacional. Este artículo describe los antecedentes para el requerimiento de dichos terminales e informa sobre los resultados técnicos obtenidos.

La experiencia práctica obtenida ha hecho posible definir las características deseables en terminales operacionales de este tipo, los cuales se consideran en detalle.

Este artículo describe brevemente los objetivos principales de las pruebas, las transmisiones efectuadas y algunos de los resultados obtenidos. Estos resultados confirman la practicabilidad de introducir un servicio nacional de televisión de difusión por satélite en Europa fundado en el plan adoptado en la Conferencia de Radio Administrativa Mundial de 1977.

Pruebas de Propagación

Resumen

Este artículo presenta los resultados de los experimentos efectuados en Crawley Court durante los dos primeros años de servicio del Orbital Test Satellite (Satélite de prueba orbital).

Los experimentos emplearon transmisiones de haz de referencia en el satélite operando a nivel constante. Las variaciones de los niveles de las señales recibidas se utilizaron como medidas de la atenuación y despolarización atmosférica. Se han obtenido resultados tanto para polarización lineal como circular.

Sistema Receptor Empleando Cancelación Adaptable para Reducir Interferencia de Polarización Cruzada en Enlaces por Satélite de Polarización Doble

Resumen

La capacidad del enlace por satélite puede extenderse empleando reutilización de frecuencias. Una de tales técnicas emplea polarizaciones ortogonales dobles. Sin embargo, a las frecuencias utilizadas en sistemas modernos, la precipitación atmosférica reduce la pureza de la polarización. Este artículo describe un sistema adaptable mejorado para cancelar dicha polarización cruzada y mantener así el aislamiento de los canales. Se hallan dispuestos voltajes de control derivados de las señales del satélite para accionar una red de acoplamiento cruzado entre los canales en el receptor de modo que se cancele la señal de polarización cruzada indeseada en el canal deseado. El sistema se comprobó empleando transmisiones de televisión desde el OTS, obteniéndose una cancelación satisfactoria.

Video Codec Digital de 60 Mbit/s

Resumen

Las técnicas para la codificación digital de señales de televisión han sido objeto de estudio durante muchos años por la IBA. Los problemas especiales planteados por la tasa de bitios y las restricciones de la tasa de error de un canal de traspondedor de satélite ofrecieron un buen reto al conocimiento y experiencia ganados previamente. Por tanto se diseñó un Codec de video desarrollado específicamente para utilizar con satélite para procurar emisión de imágenes de calidad incluso durante condiciones de desvanecimiento. El prototipo resultante fue ensayado inicialmente simulando las características de un canal de satélite. Después, en 1980, se demostró con éxito en transmisiones experimentales a través del OTS.

Transmisión por Satélite de Señales de Televisión Digitales

Resumen

Este trabajo describe una serie de transmisiones de prueba de señales de televisión del sistema I PAL codificado digitalmente a 60 Mbit/s empleando el OTS.

Se consideran varios aspectos del sistema de modulación QPSK (manipulación por desplazamiento cuadrifásico) empleado, y del canal del satélite, presentándose los resultados.

Se da los resultados de pruebas subjetivas del sistema, haciéndose una comparación entre la transmisión de televisión FM analógica y digital por satélite.

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